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Environmental Sciences Division

Environmental Data Package for the White Wing Scrap Yard (WAG 11)

W. J. Boegly, Jr.
G. K. Moore

Environmental Sciences Division
Publication No. 3125

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ENVIRONMENTAL DATA PACKAGE FOR THE WHITE WING SCRAP YARD (WAG 11)

W. J. Boegly, Jr. and G. K. Moore*

Environmental Sciences Division
Publication No. 3125

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NUCLEAR AND CHEMICAL WASTE PROGRAMS
(Activity No. KG 02 00 00 0; ERKG002)

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ABSTRACT

This environmental data package was prepared as part of the effort to meet regulatory requirements for remedial action under Section 3004(u) of the Resource Conservation and Recovery Act (RCRA). The report covers the White Wing Scrap Yard which is the only Solid Waste Management Unit (SWMU) in Waste Area Grouping (WAG) 11. ORNL has recommended that a remedial investigation be conducted to identify the nature of the remedial actions required for WAG 11.

The purpose of the environmental data package is to provide background information on the geology and hydrology of the WAG 11 area, as well as information on releases and inventories of radionuclides and hazardous materials for individual sites within WAG 11 that will be required for additional remedial action evaluations. Areas where additional site information will be required are also identified.

The data package indicates that although most of the large scrap items that were stored at the site have been removed, only limited information exists on the inventory of radionuclide and hazardous waste constituents that may remain at the White Wing Scrap Yard. Sampling of stream gravels has indicated the presence of RCRA metals and limited groundwater samples have indicated the presence of organics. The source of these materials remains unknown. Evaluation of existing geologic and hydrologic information on WAG 11 indicates that there is sufficient information available to characterize the site; however, it is possible that additional information regarding the presence of faults and cavities within the WAG may be required to determine the remedial actions required. It may also be necessary to conduct limited geophysical surveys to verify the absence of buried scrap metal.

ENVIRONMENTAL DATA PACKAGE -- WHITE WING SCRAP YARD (WAG 11)

W.J. Boegly, Jr. and G.K. Moore

1.0 Introduction

U.S. Department of Energy (DOE) facilities are required to be in full compliance with all federal and state regulations. In response to these requirements, the Oak Ridge National Laboratory (ORNL) has established a Remedial Action Program (RAP) to provide comprehensive management of areas where past and current research, development, and waste management activities have resulted in residual contamination of facilities or the environment. The primary objective of the RAP is to clean up releases of hazardous waste or hazardous constituents that threaten human health or the environment (Trabalka and Myrick 1987).

The initial ORNL remedial action strategy was based on the guidance of DOE Orders 5820.2 (Surplus Facilities Management) and 5480.14 [Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA)]; the Resource Conservation and Recovery Act (RCRA) was believed to apply only to a limited number of sites. As a part of this strategy, individual sites were being addressed according to estimated priorities for site characterization, remedial actions, and decommissioning/closure planning. In 1984, the RCRA was amended to establish broad new authorities within the Environmental Protection Agency (EPA) RCRA Programs. One of these new authorities was Section 3004(u), which stipulates that any hazardous waste management permit issued after November 8, 1984, require corrective action for all releases from solid waste management units at the facility. In a memorandum to DOE on April 1986, EPA expressed concern about the length of time required to implement DOE Orders and elected to enforce regulatory requirements for remedial actions through its amended RCRA authority (Scarbrough 1986).

Prior to the Hazardous Solid Waste Amendments (HSWA), EPA's authority to require corrective action for releases of hazardous constituents was limited to ground water releases from units that were covered by RCRA permits (Part 264, Subpart F). Since passage of the HSWA, EPA's authority has been extended to releases to all media and all units at a RCRA facility regardless of when they were used or whether they are covered by a RCRA permit (USEPA 1986).

1.1. Description of ORNL's Approach to Compliance with 3004(u)

The ORNL area is characterized by complex hydrogeologic conditions. and previous studies have shown that a strong coupling generally exists between the shallow groundwater and surface drainage systems (Trabalka and Myrick 1987). It is felt that reliance on groundwater monitoring as prescribed by RCRA regulations would not be adequate or effective under ORNL site conditions; a combination of surface and groundwater monitoring should be more effective in meeting the principal performance objective of RCRA regulations, the protection of human health, and the environment (Trabalka and Myrick 1987).

According to RCRA Facility Assessment Guidance, a Solid Waste Management Unit (SWMU) is defined as: "any discernable waste management unit at a RCRA facility from which hazardous constituents might migrate, irrespective of whether the unit was intended for the management of solid and/or hazardous waste. This definition includes containers, tanks, surface impoundments, waste piles, land treatment units, landfills, incinerators, and underground injection wells, including those units defined as regulated units under RCRA. Also included are recycling units, wastewater treatment units and other units which EPA has generally exempted from standards applicable to hazardous waste management units, and areas contaminated by routine, systematic, and deliberate discharges from process areas." The definition does not include accidential spills from production areas and units in which wastes have not been managed (e.g., product storage areas) (EPA 1986).

As the first step in identifying compliance requirements under RCRA 3004(u) for ORNL, a listing of all known active and inactive waste management areas, contaminated facilities, and potential sources of continuing releases to the environment was prepared. Included in this list were waste collection and storage tanks, solid waste storage areas (SWSAs), waste treatment units, impoundments, spill sites, pipeline leak sites, underground injection wells, and areas of known contamination within buildings. Although some of the identified sites might not be regulated under 3004(u), they were included in the site listing in order to maintain a comprehensive inventory of all ORNL sites that might require some form of remedial action.

The listing compiled for ORNL includes about 250 sites which might be considered for 3004(u) remedial action (ORNL 1987a). Because of the complex hydrogeology of ORNL and the large number of sites involved, the ORNL sites have been grouped into 20 geographically contiguous and hydrologically defined Waste Area Groupings (WAGs) [see Trabalka and Myrick (1987) for a detailed discussion of the rationale used in developing and defining the WAG concept]. Fig. 1 shows the locations of the 20 WAGs. This Environmental Data Package covers the White Wing Scrap Yard (WAG 11).

1.2. Purpose of the Environmental Data Package

As currently implemented, the 3004(u) corrective action program consists of four phases: (1) a RCRA Facility Assessment (RFA) to identify releases or potential releases requiring further investigation, (2) a RCRA Facility Investigation (RFI) to fully characterize the extent of releases, (3) a Corrective Measures Study (CMS) to determine the need for and the extent of remedial measures (this step includes the selection of appropriate remedies for all problems identified), and (4) Corrective Measures Implementation to design, construct, maintain, and monitor the performance of the measure(s) selected (EPA 1986).

Based on information developed by ORNL as input to the RFA, it appears that the White Wing Scrap Yard (WAG 11) represents a source of continuing release under 3004(u) and that an RFI will be required (ORNL 1987a,b). The purpose of the environmental data package is to provide background information on the geology, hydrology, soils, and geochemistry of the WAG 11 area, as well as information on releases and inventory of hazardous materials in WAG 11 that will be required for the preparation of an RFI. Also identified are areas where it appears that additional information will be required.

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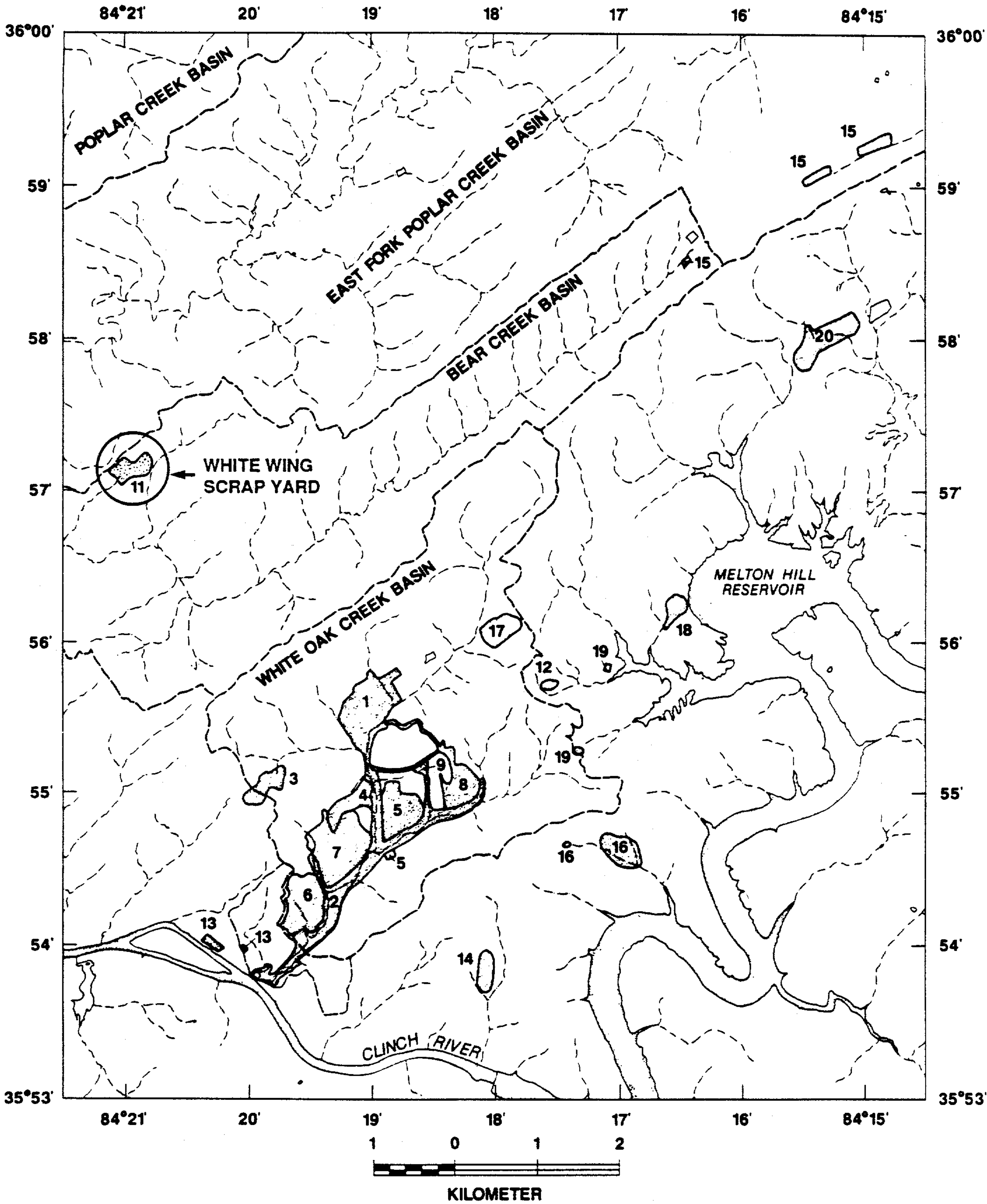

Fig. 1. Locations of the 20 Waste Area Groupings (WAGs).

1.3 Description of WAG 11

WAG 11 (White Wing Scrap Yard) is a roughly 30.4 acre, largely wooded area, that is located in the McNew Hollow area on the western edge of East Fork Ridge (Grizzard 1986). It is 1 mile (1.6 km) east of the junction of White Wing Road (Highway 95) and the Oak Ridge Turnpike, and is roughly contained within administrative grid coordinates N34,500-N35,800 and E27,500-E29,250 (see Fig. 2). There is only one SWMU in Wag 11; the approximate area used for scrap storage was 25 acres.

White Wing Scrap Yard was used for the above ground storage of contaminated material from the Oak Ridge Gaseous Diffusion Plant (ORGDP), the Electromagnetic Separations Plant (Y-12), and ORNL. The material stored at the site by ORNL (estimated to be 500,000 ft^3) was reported to consist of mild steel tanks 10 ft in diameter and 40 ft long, dump trucks, two pieces of earth-moving equipment (one weighing approximately 22 tons), large glass lined tanks, carcasses of walk-in hoods, small stainless steel and mild steel support frames, and mild steel, stainless steel, and aluminum of many sizes and shapes (Gissell 1968). Reprocessing cell vessels removed during the clean up of Building 3019 at ORNL were also stored at the site. No description exists for the materials stored by ORGDP or Y-12.

The site began receiving material in the early 1950s; however, the precise dates of material storage are uncertain, as is the time when the area was closed to further storage. During active use, one part of the scrap yard (north of "Hot Yard" road) was enclosed by a chain link fence and the remaining part (south of the road) with a barbed wire fence (Fig. 2); however, these fences were removed during the site

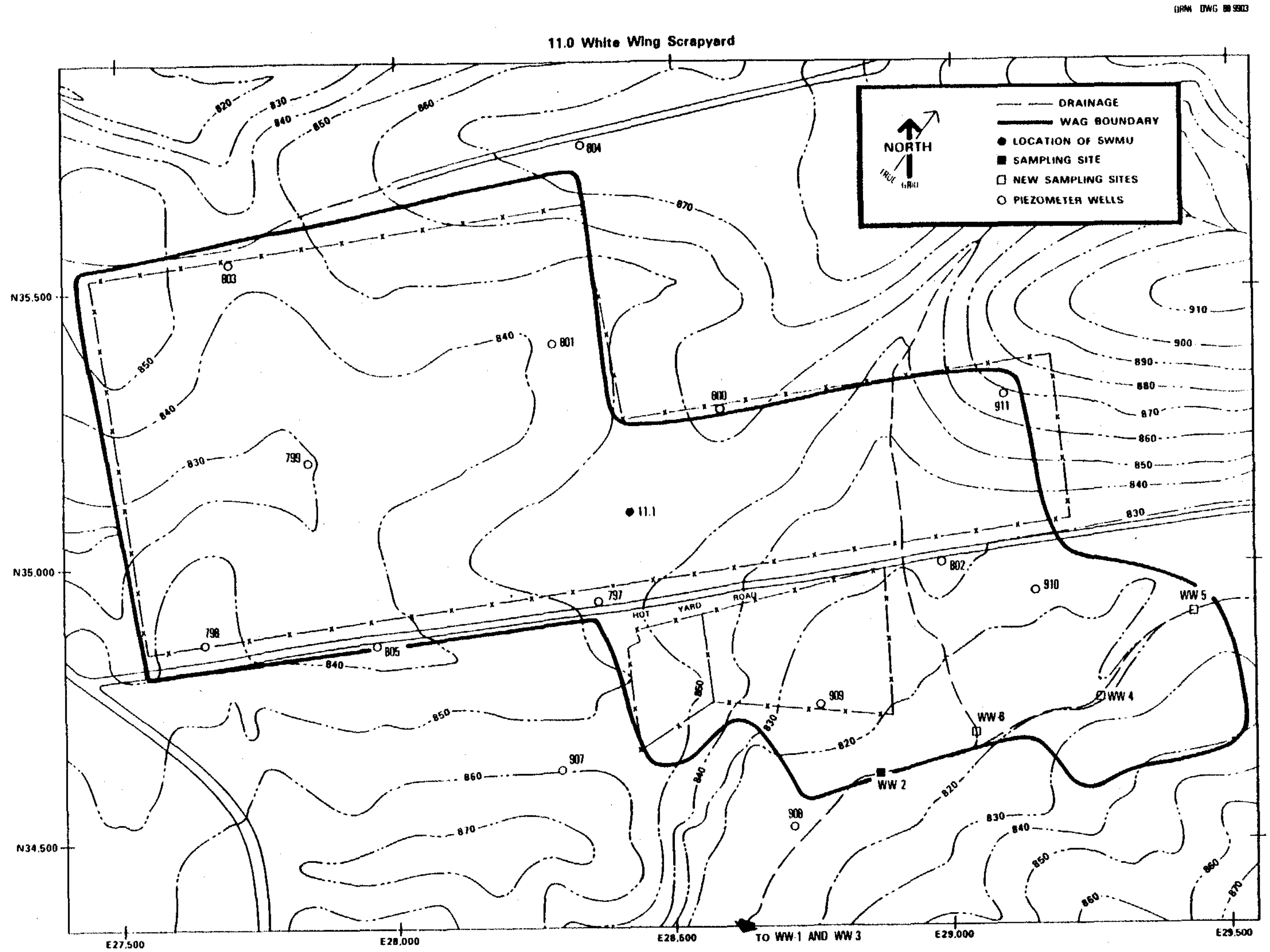

Fig. 2. Location of White Wing Scrap Yard (WAG 11).

cleanup and the area is currently unfenced. It is reported that the area north of the road was used by the ORGDP and Y-12, and that the area south of the road was used by ORNL. The area is currently overgrown with weeds, trees, and other types of vegetation. The amount of material remaining in the area is not known; however, small pieces of scrap (metals and plastic) appear on the surface over much of the site.

In 1966, efforts were begun to clean up the area. The apparent reason for the clean up was the proposed relocation of White Wing Road. Contaminated scrap materials were removed and buried in ORNL's SWSA-5, and the uncontaminated material was sold to a contractor for scrap recovery. Site clean up continued into March of 1970, and in October 1970 removal of about 6,000 yd^3 of contaminated soil from the southern portion of the site was initiated. Following removal of the contaminated soil, the entire site was surveyed for residual radionuclide contamination and then abandoned.

1.4 Known or Potential Releases from WAG 11

In the fall of 1986, Morrison and Cerling (1987) performed a limited sampling program using water, mud, and stream sediment samples from two locations adjacent to WAG 11 in order to identify whether hazardous materials and radionuclides have been, or are being, released from the scrap metal yard. One site (WW-2) was a moist creek bed within the scrap yard and the second site (WW-1) was located south of the yard where the stream passes under Highway 95. At Site WW-1 the creek flow was less than one gal/min and was backed up into a pool (~0.5 m deep) about 5 meters west of the bridge on Highway 95. Samples of stream gravels and dark mud were collected at WW-1 and WW-2, and water samples were taken from the pool at WW-1 (no flow existed at WW-2 at the time sampling was performed).

Table 1 summarizes the results of the preliminary sampling studies. For the extractable metals from the stream gravel samples, only nickel was found in concentrations exceeding background. Whether this is because of releases from the scrap yard or the natural environment cannot be determined from the survey data. Radionuclide concentrations in the stream gravels were below detection limits for ^{60}Co and ^{137}Cs; however, the samples taken at Site WW-1 showed an average concentration of ^{90}Sr of 38 Bq/kg. This suggests a possibility of ^{90}Sr release from the scrap yard. In addition, one water sample from Site WW-1 had a low (0.25 Bq/L) but detectable concentration of ^{90}Sr.

Organic 26B (Di-n-butylphthlate) was the only organic detected in two black mud samples (one from each site). Phthlate, a component of plastic materials, is common in sediments; however, the concentrations are relatively low.

In summary, Morrison and Cerling stated that except for the possibility of Ni and ^{90}Sr, no significant contamination was observed for WAG 11. They suggested that the source of the Ni or ^{90}Sr contamination could be determined by a follow-up sampling program using sites upstream from WAG 11 as control points.

The follow-up sampling program was conducted in May 1987, and the results are presented in Table 2. Five sites (Fig. 2) were sampled, including one site (WW-2) sampled in the previous survey. Sites WW-2, WW-6, and WW-4 are located within the WAG boundary. Site WW-5 is slightly upstream, and W-3 is downstream south of the scrap yard. For

Table 1. Preliminary stream gravel contaminant survey results from WAG 11 in 1986

Element	BKGD	WW-1	WW-2
		Gravels[a]	
^{60}Co[b]	<2	<6	<6
^{90}Sr[b]	<10	38 ± 40	17.3 ± 1.5
^{137}Cs[b]	3	<7	<7
Cd[c]	0.5	d	d
Cr[c]	0.05	d	d
Cu[c]	0.9	d	1.5
Ni[c]	0.6	8.2 ± 3.3	11.6 ± 3.2
Zn[c]	9	9.3 ± 2.9	8.4 ± 1.1
		Water (Bq/L)	
^{60}Co	<0.2	<0.3	
^{90}Sr	<0.2	<0.25	
^{137}Cs	<0.2	<0.4	
		Organics (ug/kg)	
Di-n-butylphthalate		540	850

[a]Concentrations reported on basis of wet weight of gravel sample. Radionuclides in Bq/kg. Metals in ug/g.

[b]Backgrounds estimated for counting procedure used in this study.

[c]Backgrounds estimated from several uncontaminated samples.

[d]Not detected

NOTE: Site WW-1, 3 samples. Site WW-2, 1-3 samples. No water sample taken at WW-2.

Source: Morrison and Cerling 1987.

Table 2. Survey results from WAG 11 in 1987

Element	BKDG	WW-2	WW-3	WW-4	WW-5	WW-6
			Gravels[a]			
^{239}Pu	0.41	0.04 ± 0.19	0.06 ± 0.12	<0.05	---	0.05 ± 0.13
^{238}U	26.2	66 ± 3	6.4 ± 1	14	---	3.8 ± 0.9
^{90}Sr[b]	10	0.3 ± 4.5	7.9 ± 6	6.0	---	2.5 ± 4.1
Cd[c]	0.05	0.40	0.27	0.22	0.13	0.20
Cr[c]	0.4	0.81	1.1	0.47	0.46	0.45
Cu[c]	0.5	2.8	1.1	0.79	1.5	0.76
Ni[c]	4.8	12	4.2	12	6.6	10
Pb[c]	2.0	3.6	<2.0	<2.0	<2.0	<2.0
Zn[c]	3.8	29	6.5	10	6.7	11
			Water (Bq/L)			
^{239}Pu	---	---	<0.01	<0.01	---	<0.01
^{238}U	---	---	0.014 ± 0.005	0.0005 ± 0.0044	---	0.0036 ± 0.0061
^{90}Sr	<0.2	---	0.09 ± 0.12	0.06 ± 0.11	---	0.12 ± 0.12
			Organics ($\mu g/kg$)			
Di-n-butylphthalate		---	4400	4400	---	---

[a] Concentrations reported on basis of dry weight of gravel sample. Radionuclides in Bq/kg. Metals in $\mu g/g$.

[b] Backgrounds estimated for counting procedure used in this study.

[c] Backgrounds estimated from several uncontaminated samples. Values are those typical for Conasauga shale.

the extractable metals from the stream gravel samples, concentrations of Cd, Cu, and Zn were 5 to 8 times background levels at WW-2. Cadmium exceeded background levels in all samples but was the highest at WW-2. Remaining metal concentrations that were detected did not exceed 2 times background at any of the sites.

Radionuclide concentrations in the stream gravels were below background levels in most samples. The concentrations of ^{238}U were about 2.5 times background at site WW-2, and ^{90}Sr levels were 2 to 3 times background at WW-3 and WW-4.

The only organic detected in the sediment samples was di-n-butylphthalate, a component of plastic materials that is common in sediments.

Groundwater samples were taken as a part of the follow up survey from selected piezometer wells in WAG 11, and the results from a metals analysis are summarized in Table 3 (for well locations, consult Fig. 2). Most of the values obtained from the downgradient wells are not significantly above those observed in the upgradient well; however, the concentration of chromium in the upgradient well is above the National Interim Primary Drinking Water Standard (NIPDWS). Magnesium concentrations in downgradient wells ranged from 20 to 140 times the value observed in the upgradient well.

Analysis of groundwater samples for volatile and semivolatile organic compounds established the presence of three volatile contaminants, methylene chloride, trichloroethylene, and acetone, at concentrations of 6 ppb, 184 ppb, and 23 ppb respectively. Only methylene chloride was detected in more than one sample. Concentrations of all the semivolatile organics were below detection limits. The concentration of

Table 3. Survey results from piezometer wells around WAG 11

WAG 11	Metals[a] (mg/ml)							
	Al	Ba	Cu	Cr	Fe	Mg	Mn	Zn
Well No.								
797	1.3	0.089	0.063	nd	1.3	19	0.076	0.035
802	0.57	0.029	0.054	nd	0.37	14	0.048	0.033
805	0.85	0.031	0.010	0.084	0.97	2.7	0.044	0.030
804[b]	1.2	0.083	0.059	0.35	0.46	0.13	0.028	0.021

[a] Only those metals that were detected in at least one sample are included.

[b] Upgradient wells.

nd not detected

trichloroethylene is significantly above the recently determined allowable limit of 5 ppb in drinking water.

Based on the results from previous scoping studies (Morrison and Cerling 1987) and the results of follow up sampling of WAG 11, it appears that WAG 11 is not a significant source of hazardous constituents. There remain, however, uncertainties concerning the source of elevated levels of Cr, Cd, some organic contaminants, and surface radiation hot spots. Further investigations are needed to resolve these concerns.

2.0 Current Status of Information on WAG 11

2.1 Source term

The waste stored at WAG 11 was mainly metal, glass, concrete, and miscellaneous trash with alpha, beta, and gamma contamination. The source and original usage of most of the stored material in the Scrap Yard has not been documented. However, an examination of internal correspondence related to the potential cleanup of the site indicates that concerns were expressed regarding security (classified materials), theft of valuable materials (copper and other metals), and potential radiation exposures (both internal and external). Contamination of the ORNL reactor cell vessels stored at the site was estimated not to exceed 25 grams of ^{239}Pu (Davis 1967). Information regarding the storage of RCRA hazardous wastes or the storage of scrap contaminated with hazardous constituents has not been found.

Some indication of the radionuclide contamination of the White Wing Scrap Yard was reported in an internal ORNL memorandum written on June 24, 1971 (Clark 1971) after most of the scrap stored on the surface had been removed:

> This memorandum contains a summary report of the radioactive contamination conditions existing at the area known as the White Wing Scrap Yard in mid-1971. The information is based upon survey work and observations made during the removal of the contaminated material from the area during 1970, during clean-up efforts in the area south of the access road early in 1971, and during a directed survey effort made on June 5, 1971.

The area south of the road, while much smaller in extent, originally (prior to scrap removal and preliminary clean-up) contained much more intensive contamination. Several (five or more) spots (2 to 3 feet in diameter) gave readings up to 5 rad/hr at 1 foot above the surface. Some of these were ground into the soil and distributed by the vehicles of the scrap removal contractor during his work there, resulting in loss of identity of the spot as a discrete area. Clean-up efforts of those that could be identified later required excavations down to 5 feet in depth (in the worst case). The surface of the south storage area was scraped three times; large spots were then excavated by Gradall operations; the remaining smaller spots were removed by hand shovels until no contamination remained sufficient to give a GMSM reading above 1 mrad/hr at 1 foot above the surface. Some 172 truckloads of contaminated earth were removed during these operations. There is no doubt, however, that considerable contamination has been covered over so that above-surface contamination surveys are no longer truly indicative of sub-surface conditions in the area south of the access road. The Analytical Data Report attached shows the results of analyses on one sample from one of the spots in that area.

The Analytical Data Report sheet (for K-25 Salvage Yard sample #2) which was attached to the memorandum showed a gross gamma of 9.2×10^8 cpm/gm and gross alpha of 8.3×10^7 cpm/gm. Radionuclide analyses reported were 2.3 mCi/gm of ^{137}Cs and 1.9 mCi/gm of ^{90}Sr. Pulse height analyses showed the alpha emitters to be 85% 5.1 MEV (^{239}Pu or ^{240}Pu) and 15% 5.5 MEV (^{241}Am or ^{238}Pu).

The following information on the portion of the White Wing Scrap Yard north of the road was also included in the same memorandum (Clark 1971).

The area north of the access road, in which no clean-up effort has been made, is much larger in extent (estimated to be in the 15-20 acre range), and shows widespread contamination from above surface measurements.

> On June 5, 1971, a GMSM survey team inspected the entire area bounded by the access road on the south and by heavy timber growth on the other three sides of the approximately rectangular area. The survey paths followed were roughly linear from east to west with 5 foot north-to-south spacing between paths. The detector elements were held approximately 1 foot above the ground on all paths. Over 60 places were found (and marked with wooden stakes) where the observed readings were equal to or greater than 1 mrad/hr at 1 foot above the surface. Most of the readings noted were in the 1 to 5 mrad/hr range, but the maximum was approximately 15 mrad/hr (50 mrad/hr with detector at ground level at this point). Many other spots of lesser contamination were noticed (readings in the range from 0.2 to 0.9 mrad/hr at 1 foot above the surface). Considering the fact that the survey lines were spaced at 5-foot intervals and the distribution and number of spots found, it seems quite likely that any similar survey of the intermediate areas would give similar results. This would indicate that there are many more contaminated areas which are unmarked and that a spot decontamination effort based on the initial survey would probably be rather futile.

The memorandum concluded with the following statement in regard to residual contamination at White Wing:

> It is concluded that the entire area is quite extensively, and in some places intensively, contaminated. The principal problem south of the access road is a sub-surface condition. No conclusions regarding contamination in depth north of the road are drawn because no such investigative effort has been made there. It is known, however, that the surface contamination has been exposed to weathering effects for several years.

An aerial radiological survey of the Oak Ridge Reservation was conducted in September 1973 and repeated in November 1974 (Burson 1976). The initial survey was conducted with a fixed-wing aircraft and was designed to locate sources of radiation resulting in gamma exposure rates of 0.5 μR/h at the survey altitude of 75 m (246 ft). The second survey was conducted at the same altitude using a helicopter. Results of this survey were used to plot isopleth maps of the exposure rates at 1 m (3.3 ft) above ground surface (Fig. 3). It should be noted that

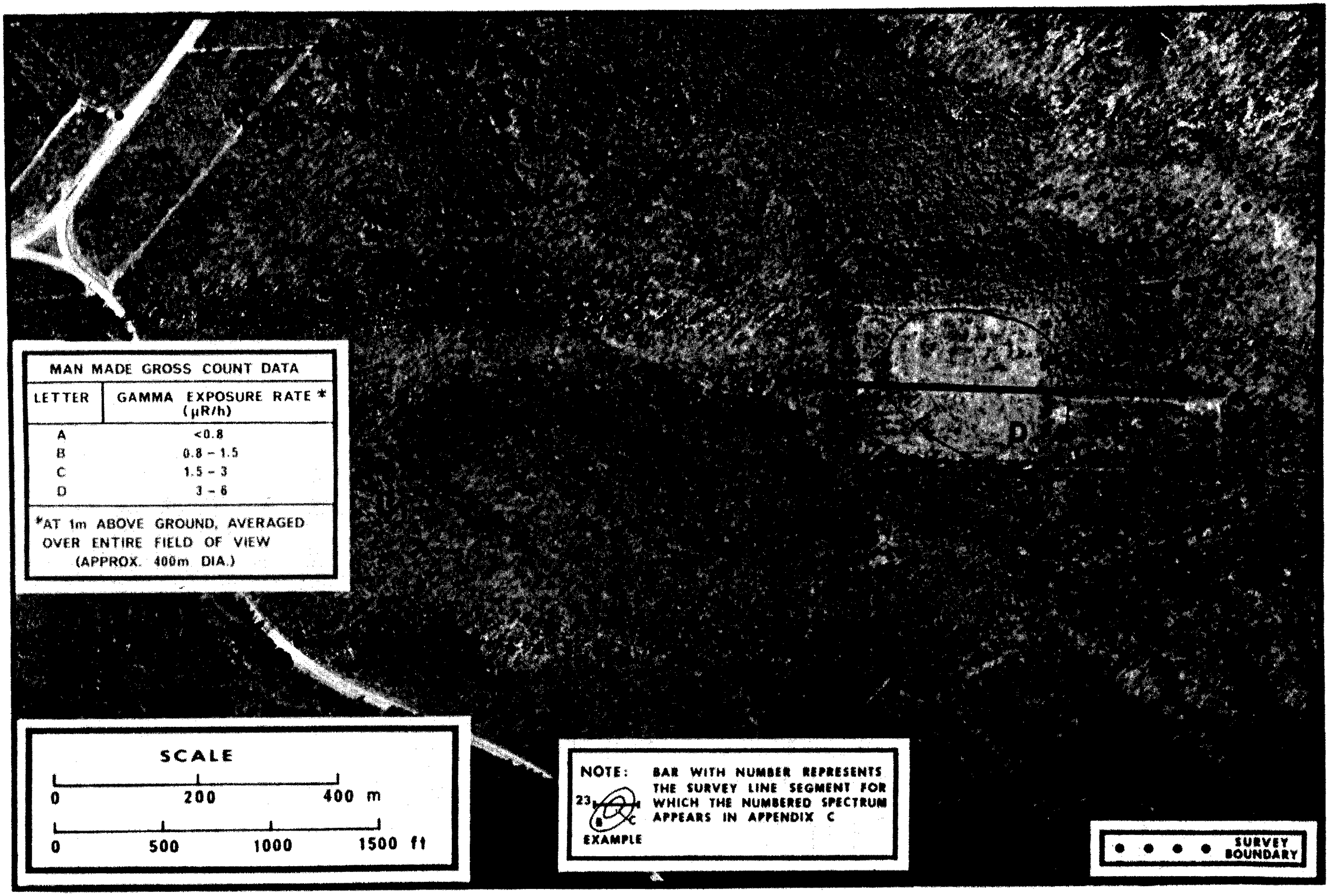

Fig. 3. Aerial Photograph of White Wing Scrap Yard in 1974 showing radiation isopleths.

the highest intensity isopleth includes most of the northern area of the scrap yard; this would appear to confirm the memorandum from Clark (1971) indicating that little or no decontamination activities (other than scrap removal) were conducted north of Hot Yard Road.

The aerial radiation survey indicated that ^{137}Cs and ^{234m}Pa were the dominant gamma sources present; analysis of the low energy portion of the spectrum indicated that ^{234}Th and ^{235}U were probably also present in the Scrap Yard (Burson 1976).

2.2 Geology

The surface trace of a part of the Whiteoak Mountain thrust fault (Fig. 4) crosses the center of WAG 11 and divides the WAG into two approximately equal areas. The Rome Formation of Lower Cambrian age occurs southeast of this fault, and the Chickamauga Limestone of Middle Ordovician age and the Reedsville Shale of Upper Ordovician age crop out northwest of the fault (McMaster 1962). The surface geology of this area has not been mapped in detail, but the Chickamauga Limestone probably includes at least units G and H of Stockdale (1951, p. 22). The geologic formations, from youngest to oldest, have been described (McMaster 1962, and Stockdale 1951, pp. 17-25) as follows:

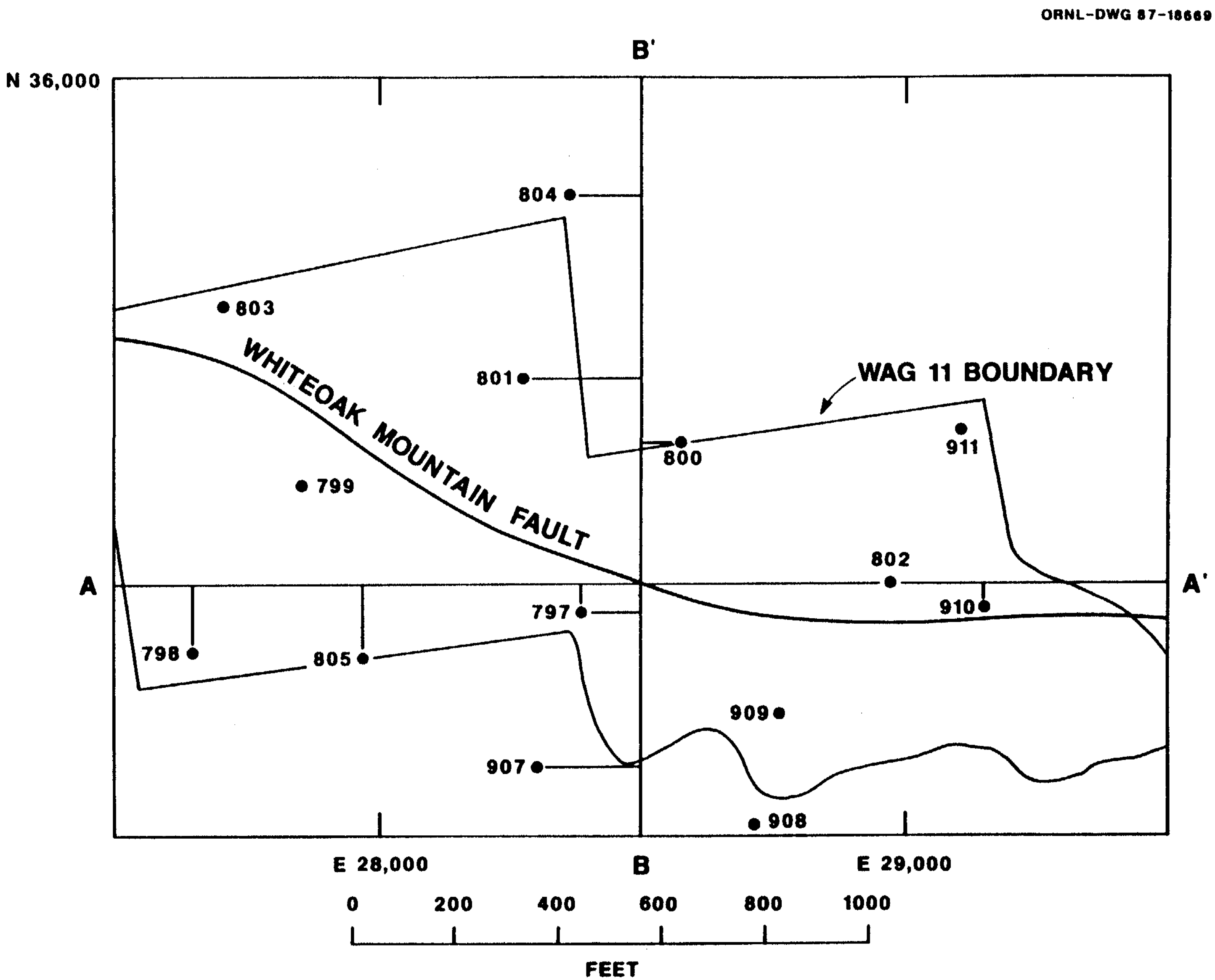

Fig. 4. Locations of piezometer wells, lines of section, and the Whiteoak Mountain Fault.

Unit	Description	Thickness (ft)
Reedsville Shale	Shale with thin limestone lenses; tan to orange-brown with black stains.	200
Chickamauga Limestone		
H	Argillaceous limestone to calcareous siltstone; gray, olive, or maroon; partly fossiliferous; thin bedded with shale partings between beds.	300
G	Limestone, dark gray to brownish gray with black clay partings between beds; dense to medium grained; thin bedded to massive. Weathers to a shaley or nodular appearance.	300
Rome Formation	Soft shale to silty shale with hard siltstone layers up to 4-ft thick; gray or greenish gray to bright maroon or red. A few lenses of dark gray dolomite. Chert cobbles in regolith.	1,000

The strike and dip of the rocks have not been measured in WAG 11. In nearby areas, the direction of strike varies but may average about N60^{o}E; the dip is vertical to 35^{o} southeast. Small faults and folds probably occur in the area but have not been mapped.

A probability plot of regolith thickness (Fig. 5) for 233 wells near ORNL shows that these thickness values represent a single lognormally distributed population in which the geometric mean is 10 ft, the thickness of the mean minus one standard deviation. Regolith is formed by solution of part of the rock matrix or of the rock cement and is removed by erosion at the land surface. Thus, the unusually thick regolith of the WAG 11 area (Fig. 6) could indicate either a less than average erosion rate at land surface or a more than average rate of new regolith formation in the recent geologic past.

Logs prepared by drillers and by geologists with MCI Consulting Engineers, Inc. during the construction of 14 piezometer wells (Fig. 4) in WAG 11 describe the subsurface characteristics of the rocks. The Reedsville Shale was not recognized in these well logs; this formation should outcrop at the

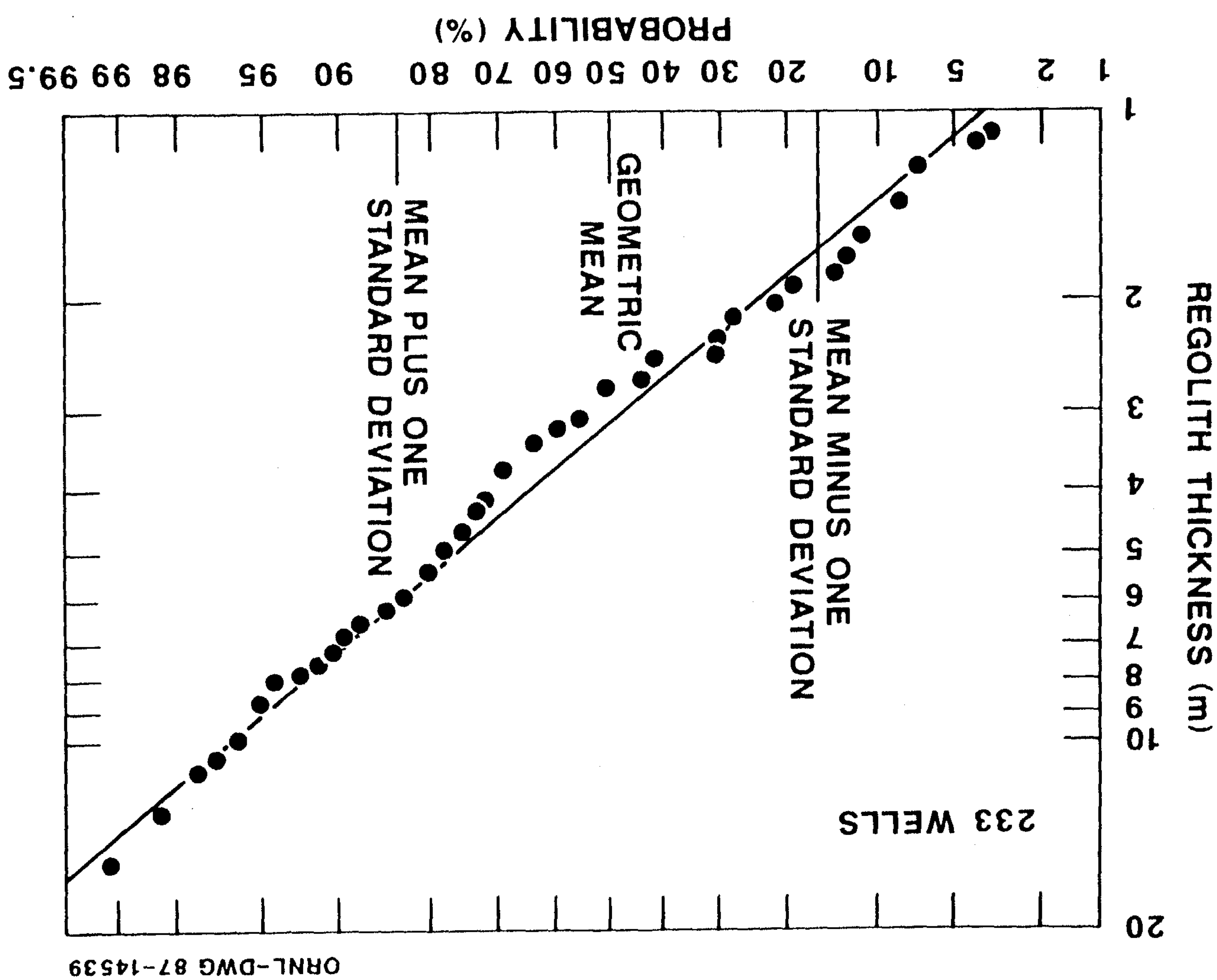

Fig. 5. Cumulative probability graph of regolith thickness in wells.

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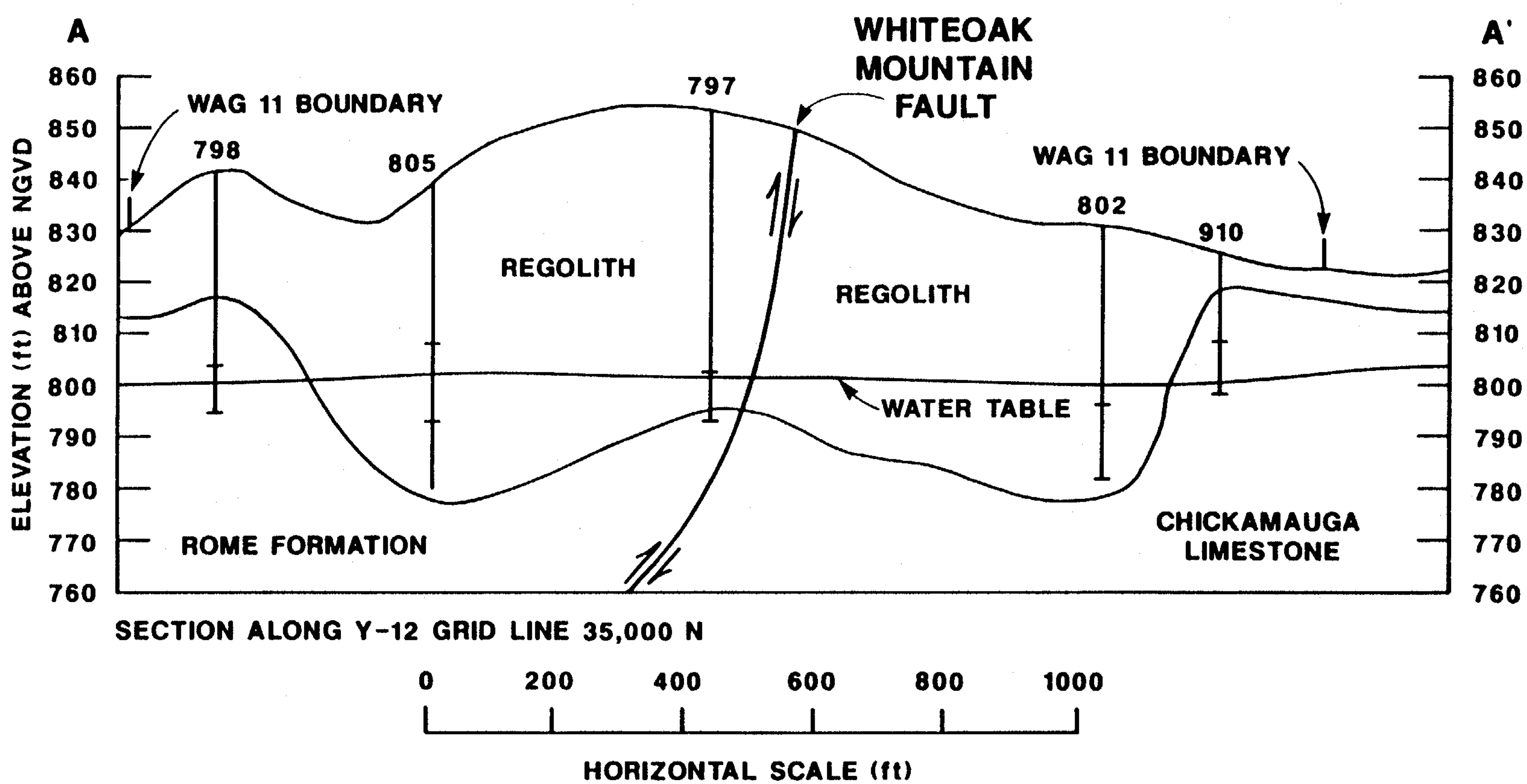

Fig. 6a. Section A-A'. WAG 11 sections showing well depth, screen intervals, water table depth, and geology.

ORNL-DWG 87-18671

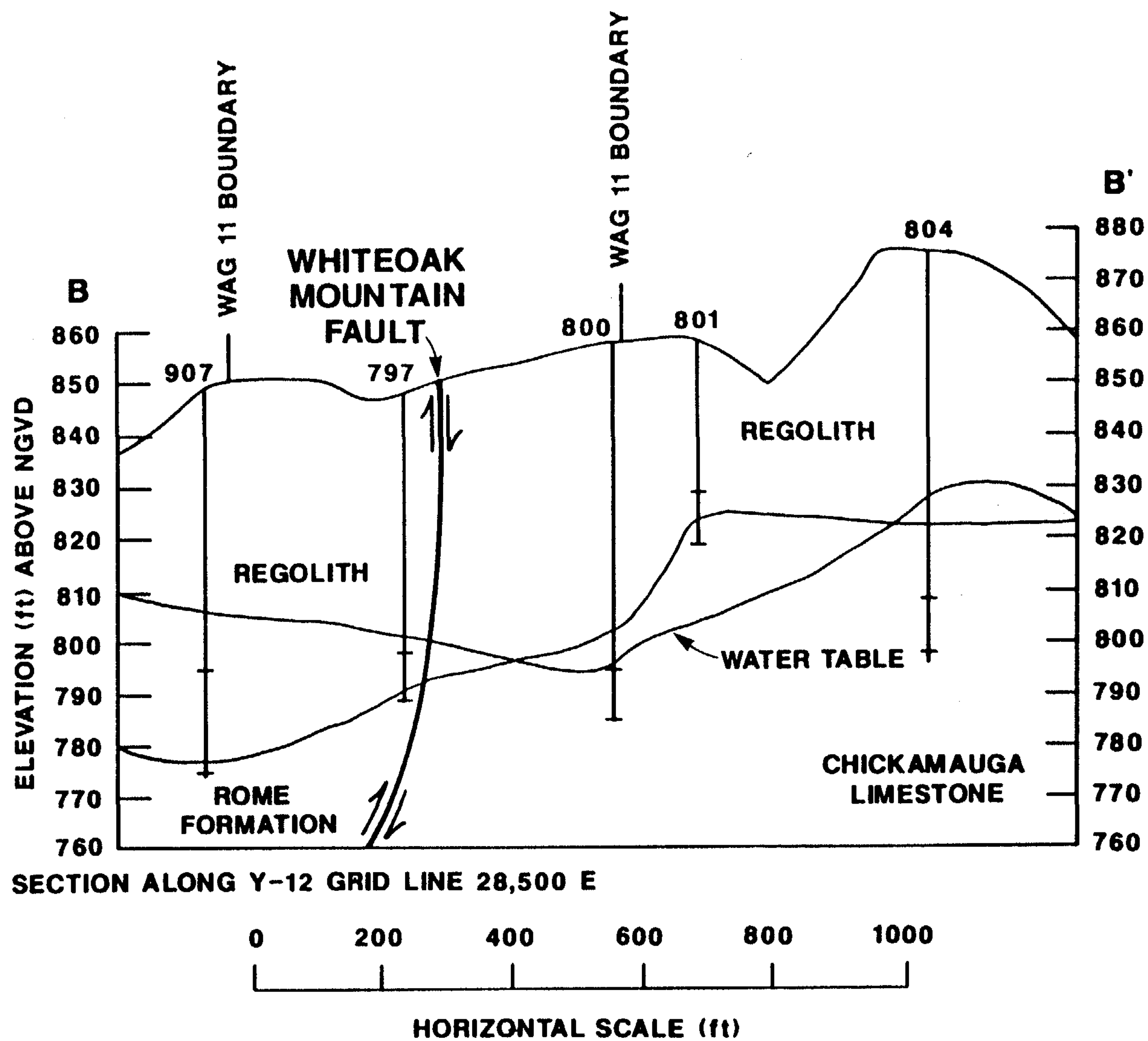

Fig. 6b. Section B-B′. WAG 11 sections showing well depth, screen intervals, water table depth, and geology.

locations of wells 804 and 911; it may constitute a part of the regolith in these areas. Cross sections (Fig. 6a and 6b) show subsurface relationships of the rock units, the regolith, and the water table in WAG 11.

Regolith in the outcrop areas of the Reedsville Shale and the Chickamauga Limestone was described in well logs as a red to brown, plastic clay in which chert gravels or nodules are common. Gravel-sized fragments of limestone and calcite in a clay matrix were described at one location. The Rome regolith was described as a crumbly (dry) to plastic clay with a wide variation in color: red, maroon, reddish brown, yellowish brown, green, grayish green, and gray. Chert fragments, gravels, or cobbles are common to rare. Groundwater velocities in two of the seven Rome regolith wells were reported to be fast enough to wash away sand that was being emplaced around the well screens. Bedrock of the Chickamauga Limestone was described in well logs as a hard, gray or olive-gray to red, fine-grained, massive limestone that has some cherty or shaley layers and a few inclusions of chert or calcite. Three of the seven wells in the Chickamauga encountered cavities 3 ft, 7 ft, and 14 ft high; the two largest cavities were described as "mud filled" and as "filled with mud and rounded chert gravel." The Rome bedrock was described as a gray to red or yellow shale with hard layers of limestone (probably siltstone).

The Whiteoak Mountain thrust fault was not encountered by piezometer wells in WAG 11. Elsewhere near ORNL, wells penetrating the Copper Creek thrust fault were reported as having impermeable zones of brecciated rock and gouge at the level of the fault and in a zone 15-70 ft above the fault (Stockdale 1951, p. 41; and Haase et al. 1985, pp. 67-69). Conditions along the Whiteoak Mountain fault are probably not similar because there is little difference in water level elevation in wells on opposite sides of this fault; the configuration of the water table (Fig. 7) also suggests that a zone near the fault may be a conduit for groundwater flow in the WAG 11 area.

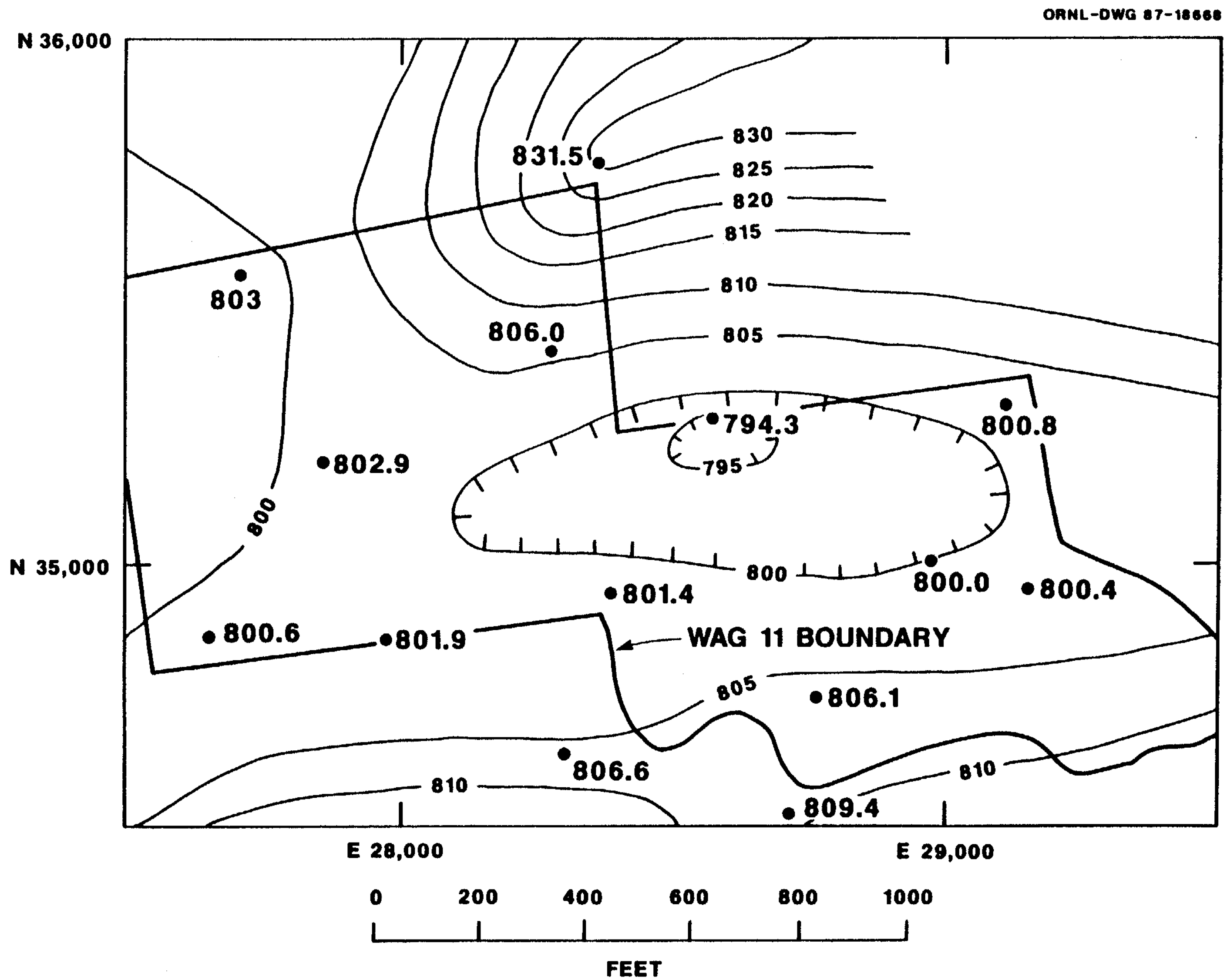

Fig. 7. Configuration of the water table in October, 1987. Elevations in ft above NGVD.

2.3 Hydrology

2.3.1 General

Mean annual precipitation in the period 1954-1983 was 52.2 in. for stations near ORNL; the minimum and maximum amounts in this same period were 35.3 and 74.8 in. of water (Webster and Bradley, 1987, p. 13). The 1986 water year was unusually dry, and only 34.5 in. of precipitation were recorded by U.S. Geological Survey at a station in WAG 5. The wettest months generally are January through March, and the driest months are August through October; in these periods, mean monthly precipitation at the Oak Ridge Station of the National Oceanic and Atmospheric Administration is 5.3-6.2 in. and 2.9-3.8 in., respectively. The monthly extremes for the Oak Ridge station are 13.3 in. for January 1954 and 0.5 in. for August 1953 (National Oceanic and Atmospheric Administration 1974, p. 378). In the dry 1986 water year, only 0.9 in. of precipitation was measured in WAG 5 during January, and 3 months (December, April, and June) had less than 2.0 in. of precipitation. The average frequencies of occurrence for various precipitation intensities over periods of 30 minutes to 24 hours are shown by McMaster (1967, Fig. 3).

Droughts lasting 7 days occur about 17% of the time, but droughts lasting 15 days occur, on an average, only 1.8% of the time (McMaster 1967, Fig. 5). In the dry 1986 water year, the longest droughts at the WAG 5 station were 18 days in January, 15 days in April-May, 15 days in June, and 17 days in July.

The mean annual runoff for streams in the ORNL area is 22.3 in. of water (McMaster 1967, p. 9). The remainder of the mean annual precipitation, about 30 in. of water, is consumed by evapotranspiration. Based on pan evaporation measurements at Norris, Tennessee, about 75% (22.5 in. of water) of the evapotranspiration occurs during the 6-month period from April through September (Tennessee Division of Water Resources 1961, p. 18). The growing season from April 1 to November 5, when potential evapotranspiration is highest, averages 220 days, (National Oceanic and Atmospheric Administration 1974, p. 373). A water-balance graph for Rogersville, Tennessee, shows that potential evapotranspiration exceeds precipitation for 5 months, from May through September, and that the main period for replenishment of the soil moisture deficit is October 1 to November 10 (Tennessee Division of Water Resources 1961, Fig. 4).

Streamflow and runoff depend upon amounts and changes in precipitation, evapotranspiration, and groundwater storage. Average quarterly runoff from the Oak Ridge area (McMaster 1967, p. 10), as a percentage of mean annual runoff, is shown below.

Quarter	Percent of annual runoff
Oct.-Dec.	17
Jan.-Mar.	49
Apr.-June	23
July-Sept.	11

A comparison of seasonal differences in precipitation and runoff shows that about 5 in. of water represent both the increase of evapotranspiration in the summer months over that in the winter months and the decrease in groundwater storage during the summer and fall.

About 30% of the WAG 11 area is covered by pine forest of small sawtimber size. The remainder of the area is covered by mixed grass, sedge, forb, brush, and young trees of various pioneer species. The grass and brush area was formerly used for surface disposal of metal scrap and has been partly regraded by shallow cut-and-fill operations. The soil appears to have a low fertility but would be expected to have a medium infiltration capacity. Also, very little of the WAG is steeply sloping; overland flow of water may be relatively small in comparison with other areas near ORNL.

An exact water budget for WAG 11 cannot be determined, but an estimated annual budget can be based on observed conditions in the area and on parameters measured in nearby areas, as follows.

INFLOW		Inches
Mean annual precipitation		52
Total Inflow		52
OUTFLOW		
Streamflow		25
Storm flow	17	
Base flow (aquifer discharge)	8	
Evapotranspiration		27
Total outflow		52

The storm-flow component of this budget includes water that infiltrates the land surface but is discharged laterally at wet-weather seeps and springs before reaching the water table. The great majority of the base-flow component is water that follows shallow flow paths to the closest seep, spring, or stream. As is discussed later, only about 2 in./year of water follows longer and deeper flow paths to larger streams.

WAG 11 lies within Bear Creek drainage basin near the junction of Bear Creek with East Fork Poplar Creek. The northwesternmost boundary of the WAG is a part of the divide between these basins. The central part of the WAG forms a drainage divide between two unnamed tributaries to Bear Creek. All surface flow is to Bear Creek along one of these two tributaries. Groundwater flow, as is discussed later, is believed to be generally toward WAG center and then toward Bear Creek along the valley of the northern tributary.

2.3.2 Infiltration and Groundwater Recharge

The processes that produce aquifer recharge are precipitation, infiltration, and percolation. The infiltration capacity of mixed grass and brush areas like those in WAG 11 has not been measured in the ORNL area. Tests in forested areas under saturated soil conditions (Watson and Luxmoore 1986, and Wilson and Luxmoore, in press) have shown a typical infiltration capacity of about 12 in./h. Other tests have shown typical infiltration capacities of about 0.021 in./h for undisturbed C-horizon soils and 0.15 in./h for trench-fill materials (Luxmoore et al. 1981, p. 688, and Davis et al. 1984, p. 72). The average infiltration capacity of the mixed grass and brush area in WAG 11 is probably in the range 1-4 in./h.

Very little infiltration occurs as intergranular flow. The porosity of clay soils is generally about 50%. However, Watson and Luxmoore (1986, p. 581) found that macropores and mesopores, which together occupy only 0.2% of the soil volume, account for 96% of the infiltration. Macropores and mesopores are not completely understood but are connected voids that may have various causes, including biochanneling, cracking, and aggregation of soil particles. The significance of this effect is that there is much less filtering of any contaminants than would be assumed by only a consideration of regolith thickness and depth to water table.

Percolation occurs through the unsaturated zone above the water table, but changes in the permeability of the flow paths occur at every level. Locally, lateral movement toward land surface may dominate at one level whereas vertical movement or lateral movement in other directions may dominate at other levels. Local flow directions may also change through time as infiltration ends and as openings drain. Flow paths thus are complex and may be tortuous in detail with numerous splits and joins. Some percolating water reaches the water table and recharges the aquifers. The remainder is discharged at wet-weather seeps and springs. The discharged water flows overland to streams.

A majority of all aquifer recharge occurs during the nongrowing season and soon thereafter, from about November 5 to April 30. During periods of intense precipitation in the growing season, some recharge reaches the water table, and water levels in many wells rise or show a slower rate of decline for a few days. However, the water levels in all wells decline, although at a variable rate, throughout the growing season because most precipitation is captured by vegetation in this period of time.

Cumulative probability plots of October depth to water (Fig. 8) and seasonal water level change (Fig. 9) for all wells near ORNL show that these parameters are lognormally distributed populations. The geometric mean depth to water is 14 ft, and the two-standard-deviation range in water depths is 6.6-30 ft. The geometric mean amount of seasonal change in water levels in wells is 3.9 ft; the two standard deviation range is 2.0-8.2 ft. In the WAG 11 area, October depths to water in wells are generally much larger than average. Ten wells have depths to water (35-70 ft) that are

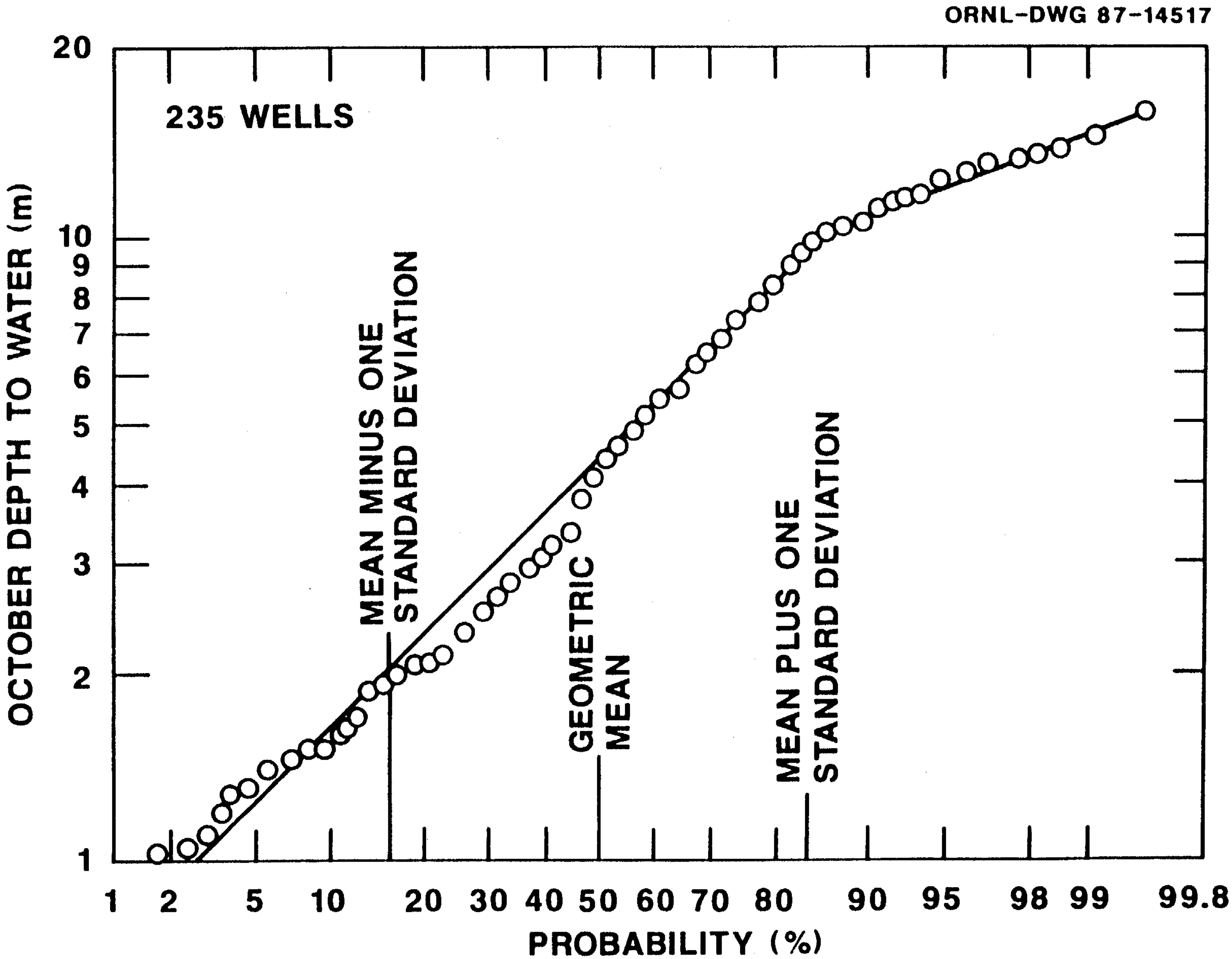

Fig. 8. Cumulative probability graph of depth to water in observation wells during October, 1986.

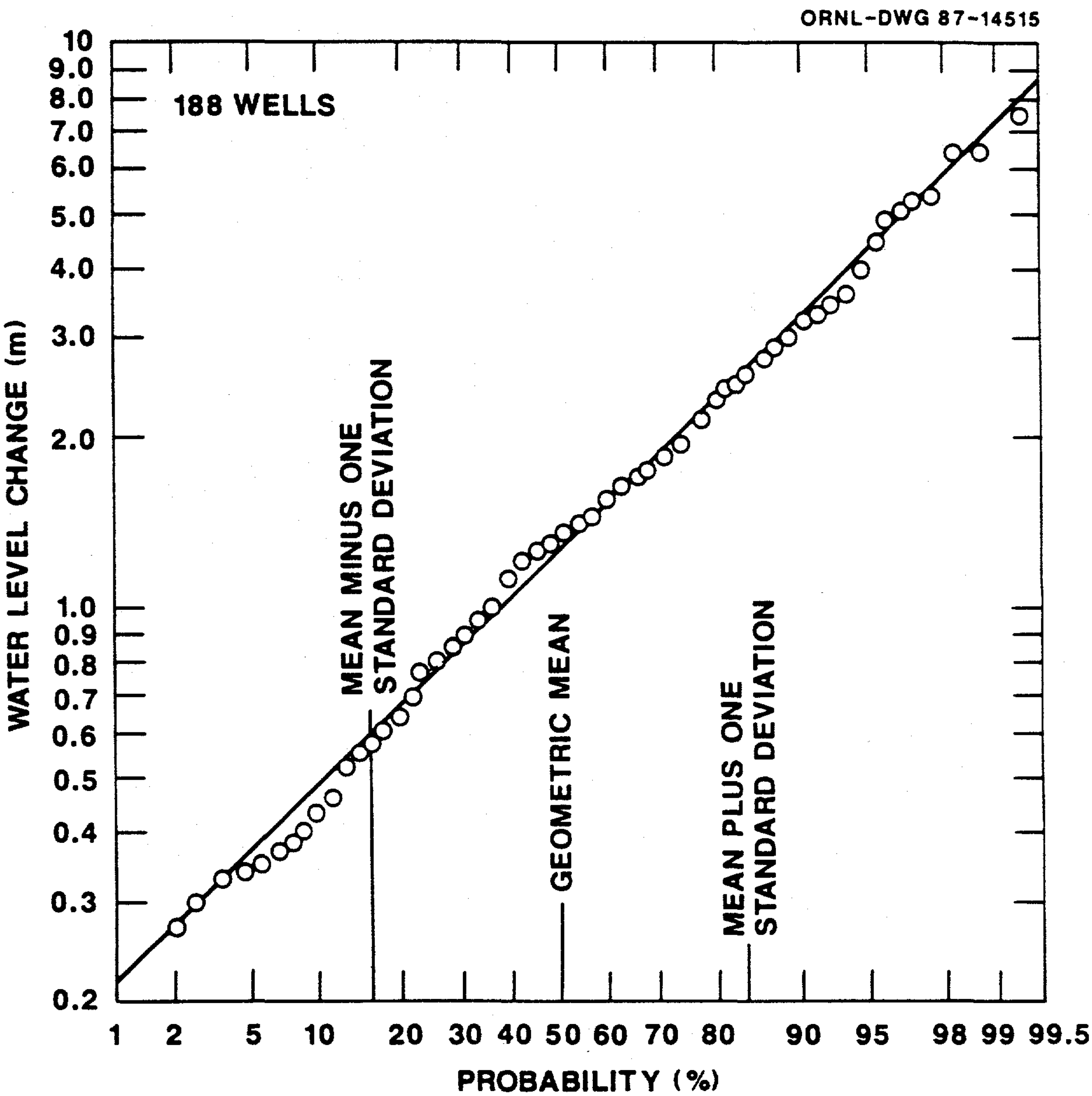

Fig. 9. Cumulative probability graph of seasonal water level changes in wells.

greater than the mean plus one standard deviation, and only one well has a depth to water less than the mean minus one standard deviation. The amount of seasonal change in water level has been measured in only eight of the 14 wells. Similarly, however, seven of these wells have a seasonal fluctuation (17-33 ft) that is larger than the mean plus one standard deviation. These characteristics suggest that groundwater conditions in the WAG 11 area are unusual; possible reasons are discussed later. The largest amounts of seasonal change in water level are near the center and near the southwestern edge of WAG 11 (Fig. 10).

2.3.3 Groundwater Occurrence

Groundwater in the clayey regolith of WAG 11 occurs in intergranular pores, in mesopores and macropores, and in a few larger openings. The hydrologic importance of these openings increases with size and flow rate because, as shown by infiltration measurements, only a very few openings may produce nearly all groundwater flow. Water velocities fast enough to wash away coarse sand were reported in Rome regolith, just above top of bedrock, in piezometer wells 908 and 909. If regolith was correctly identified at these locations, piping must have occurred to create large tubes (or vertical sheetlike openings) and turbulent flows of groundwater. Similar large openings may occur elsewhere in the WAG 11 regolith but are believed to be uncommon; such openings have rarely been reported in other areas. Any large openings in regolith are likely to represent an upward continuation of enlarged fractures and cavities in the bedrock. All other openings in the regolith are probably less than 0.03 in. in diameter or aperture; groundwater flow is laminar in openings of this size.

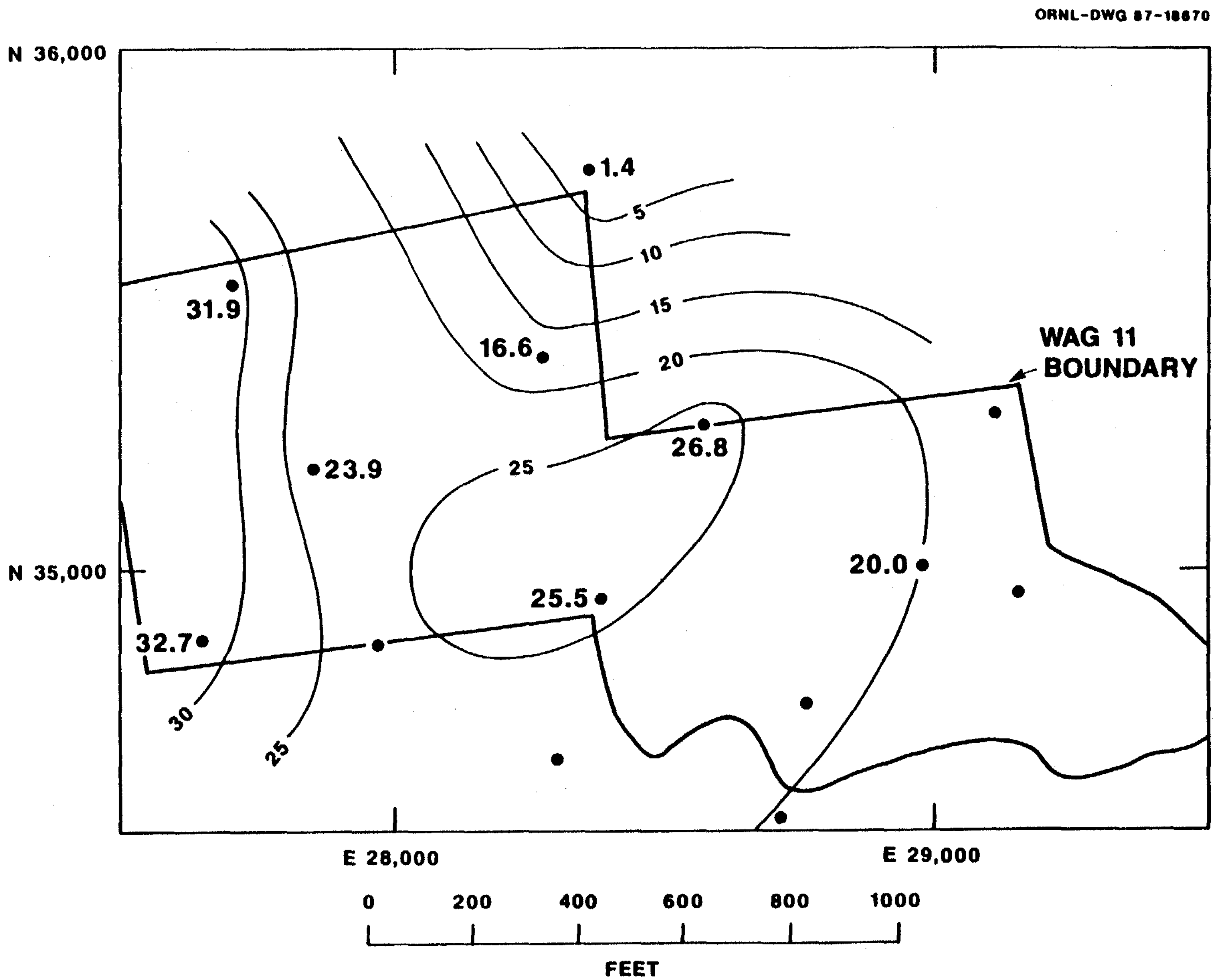

Fig. 10. Seasonal water level change (ft) in wells in WAG 11 area.

In bedrock, essentially all groundwater occurs in fractures and in a few larger cavities because the rocks have almost no primary porosity and permeability. The fractures consist of joints and faults that formed in the geologic past by extension, compression, and shear of the rocks. These processes created a large number of both isolated and interconnected fractures with a large range in aperture (gap width). Through geologic time the deposition of minerals dissolved from adjacent rocks sealed some open fractures, but other interconnected fractures form the bedrock flow paths for groundwater.

Most individual fractures are short, a few inches to several feet in length, but various joint sets form intersecting systems (Sledz and Huff 1981). One pervasive fracture set, noted by many authors, is oriented parallel to the bedding planes. The separate fractures in this set commonly occur in the partings between rock layers in the Chickamauga Limestone (R. H. Ketelle, personal communication). Another fracture set is parallel to the strike of the beds; a less common, orthogonal fracture set is parallel to the dip of the beds. These three fracture sets may be presumed to occur in the WAG 11 area, and other sets may also be present.

Cavities are formed by solution, abrasion, and a combination of these two processes. Enlargement of fractures in the rock begins with slow solution of a part of the adjacent rock mass or of the rock cement, which constitutes about 5-10% of the mass. Openings enlarged above some critical size (as determined by the prevailing hydraulic gradient) permit turbulent groundwater flow. In this case, physical erosion by abrasion increases the rate of cavity enlargement while the turbulent flows remove at least some of the resulting detritus. The remaining detritus accumulates at the bottom of the cavity and partially protects the rock surface against further solution and abrasion. Thus, most larger cavities develop mainly by abrasion and by upward erosion. If groundwater flow decreases through time because of less recharge or because of water capture by a new flow path, a cavity may be completely or partly filled by the relatively insoluble residues of the adjacent rocks.

So-called solution cavities in the Chickamauga Limestone were first described by Stockdale (1951, p. 41). Since then, cavities have also been reported in other rock units with limy layers. The size of cavities that can form in siliceous (nonlimy) rocks is unknown. Nevertheless, the largest cavities are found in the purest and most massively bedded limestones, and only a small amount of fracture enlargement is found in most siltstones, sandstones, and shales.

The water-bearing characteristics of aquifers in the WAG 11 area were examined by the drilling and testing of piezometer wells. These wells were generally drilled to the shallowest level where an inflow of water from the aquifer was detected, and thus, the characteristics of deeper levels have not been determined in WAG 11 and in most other areas near ORNL. A probability plot of depths for all piezometer wells within a 3-Km radius of ORNL (Fig. 11) shows that this parameter is lognormally distributed. The geometric mean depth is 23 ft, and the two-standard-deviation range is 11-48 ft. All piezometer wells were drilled to a level that was thought to be water-bearing, and the probability graph thus may represent the distribution of water-bearing zones with depth in most areas near ORNL. However, the graph does not accurately represent conditions in WAG 11. All piezometer wells in WAG 11 are deeper than the mean of the population, and seven wells (50%) are deeper than the mean plus one standard deviation. This difference is caused by the large depth to water in the area. All but one of the wells in the Rome Formation are screened in regolith or across the contact between regolith

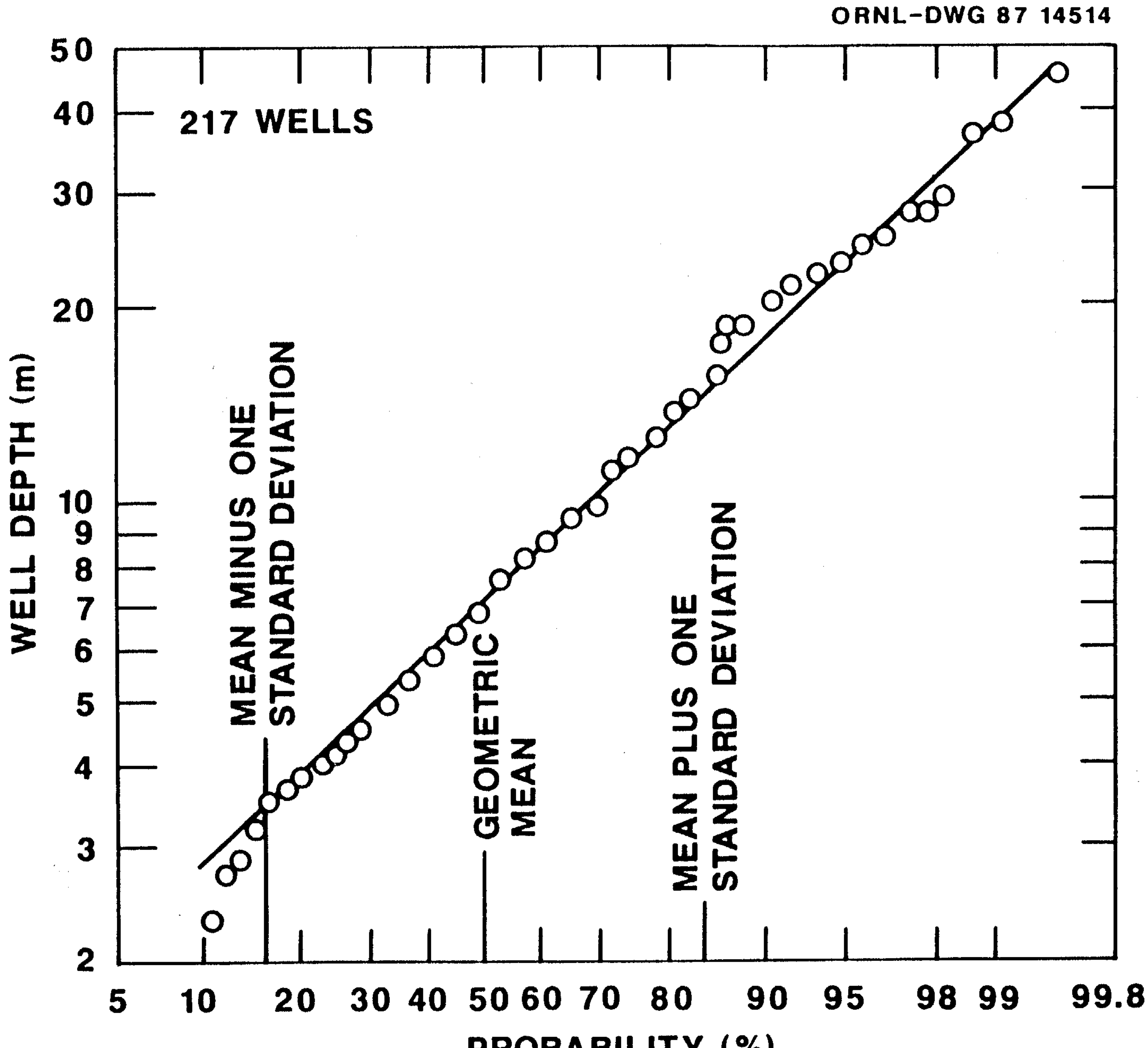

Fig. 11. Cumulative probability graph of well depths.

and bedrock; the other well was drilled through 23 ft of bedrock. Three of the Chickamauga Limestone wells are screened in regolith or across the contact with bedrock. The other four wells were drilled through 18-75 ft of rock before obtaining water.

Hydraulic conductivity, transmissivity, and aquifer thickness values (Table 4) were obtained by analysis of data from slug tests on the piezometer wells. Probability plots of hydraulic conductivity and transmissivity in other areas (Figs. 12-13) show that the populations are lognormally distributed. The geometric mean hydraulic conductivity is 0.13 ft/d, and the two standard deviation range is 0.023-0.72 ft/d. The geometric mean transmissivity is 1.6 ft^2/d, and the two standard deviation range is 0.27-9.7 ft^2/d. These parameters are somewhat more variable in the WAG 11 area than in the population. Four of 14 wells (two wells in Rome and two wells in Chickamauga) have hydraulic conductivity values smaller than the mean minus one standard deviation, and the same number of wells and values are larger than the mean plus one standard deviation. The distribution of transmissivity values in WAG 11 is similar.

The slug tests showed that two Rome wells (908 and 909) and one Chickamauga well (910) have hydraulic conductivity and transmissivity values larger than any previously measured for 306 other wells near ORNL. Each of these wells should yield more than 30 gal/min of water. The two Rome wells are those reported as having high groundwater velocities, and the Chickamauga well has a cavity from 25-28 ft. These results indicate that relatively large rates and quantities of groundwater may flow through some cavities and other enlarged openings in the WAG 11 area. Such openings may be common in the area. Considering only cavities in the Chickamauga Limestone bedrock, 24 ft of cavities in 144 ft of borehole are equivalent to a vertical spatial

Table 4. Results of slug tests on piezometer wells in WAG 11.

Well No.	Hydraulic Conductivity (m/d)	Transmissivity (m^2/d)	Aquifer Thickness (m)
797	0.013	0.029	2.2
798	0.12	0.30	2.5
799	0.0036	0.013	3.6
800	0.022	0.074	3.4
801	0.017	0.24	1.4
802	0.0090	0.063	7.0
803	0.53	1.2	2.3
804	0.0001[a]	0.001[a]	---
805	1.0	2.1	2.1
907	0.0027	0.030	11
908	6.2	46	6.3
909	7.3	40	5.5
910	5.7	37	6.5
911	0.0079	0.050	6.3
Geometric mean	0.059	0.29	3.9

[a] Data value near zero and too small for accurate determination.

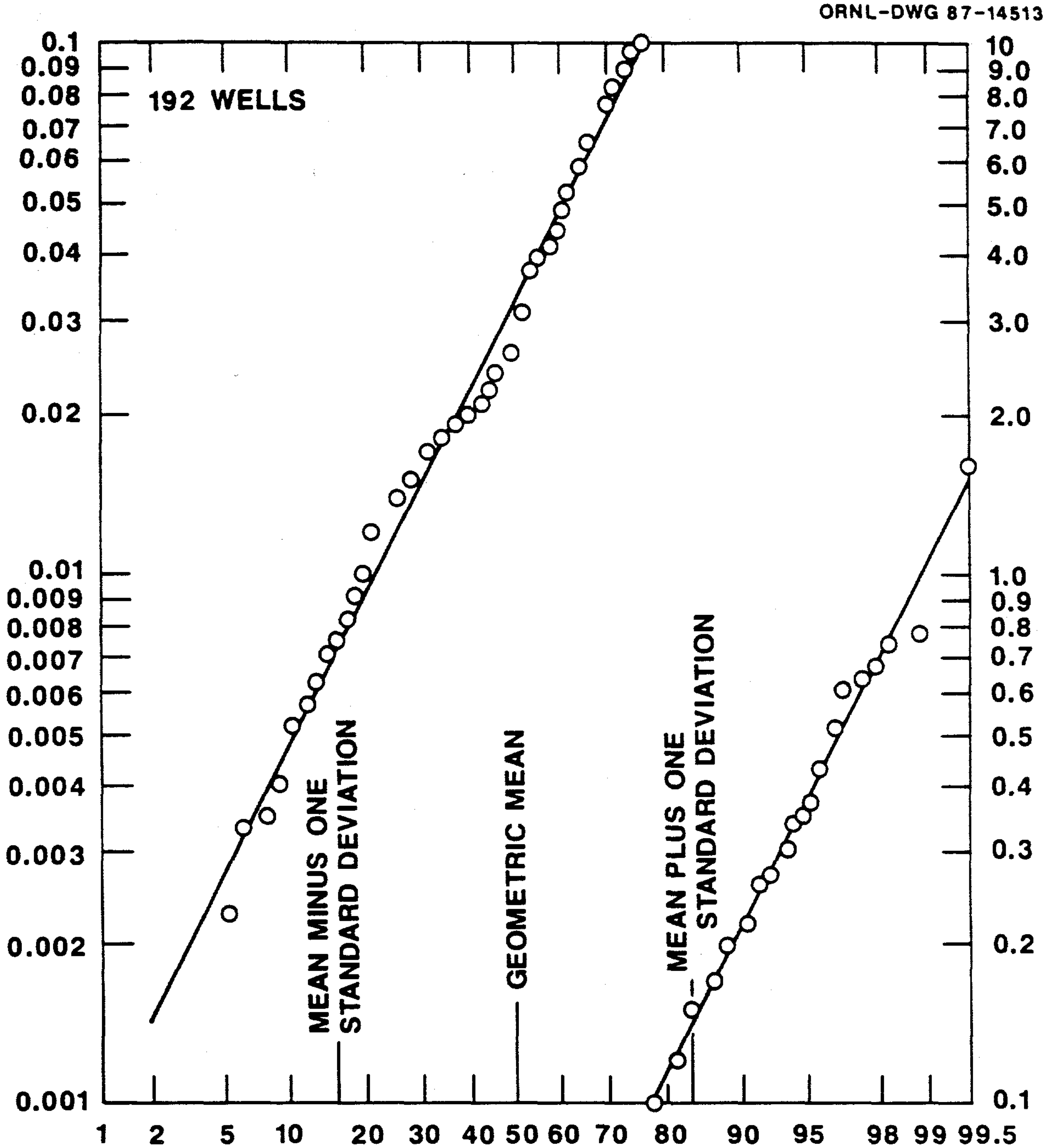

Fig. 12. Cumulative probability graph of hydraulic conductivity values from slug tests.

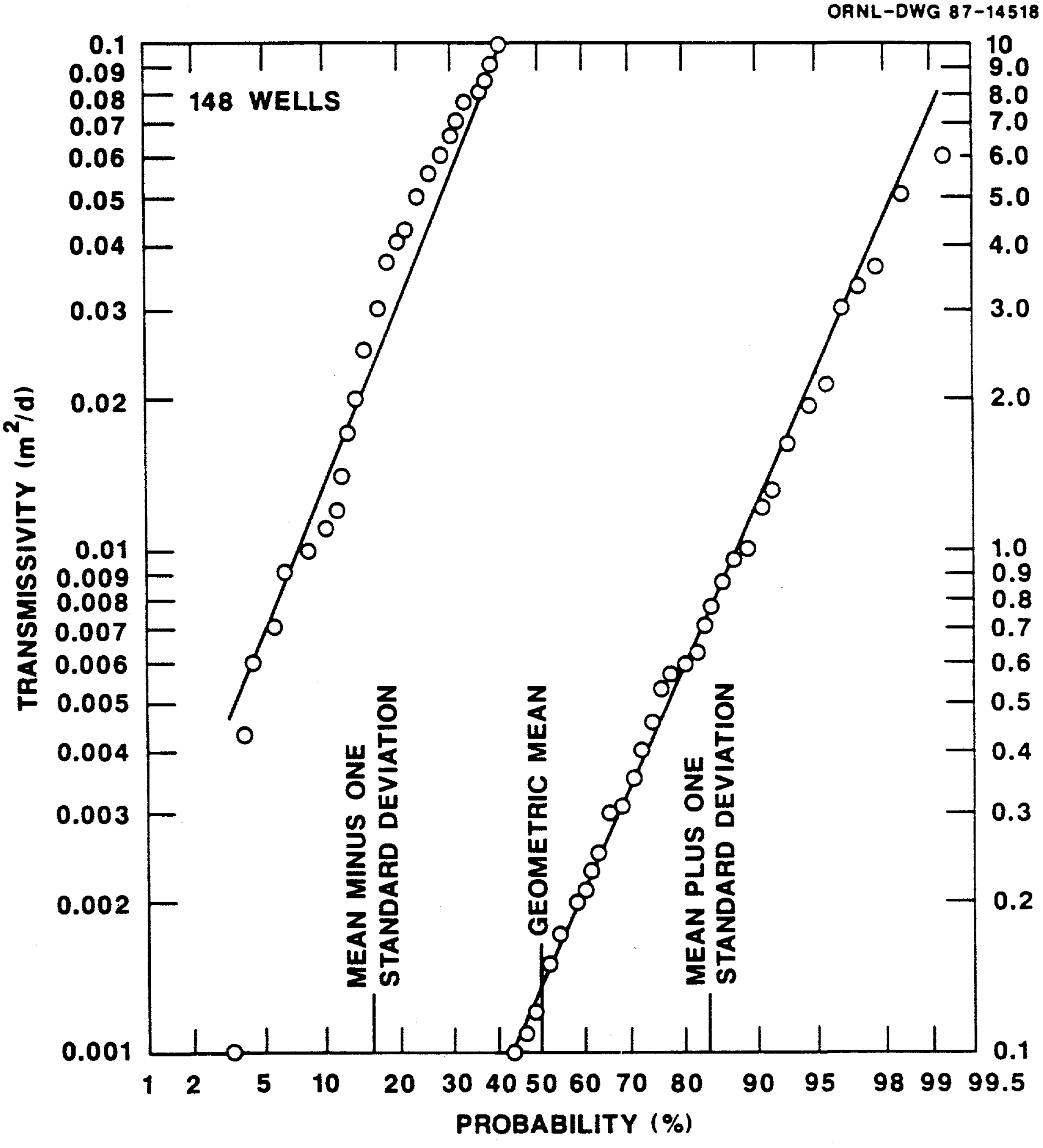

Fig. 13. Cumulative probability graph of transmissivity values from slug tests.

frequency of 0.17; the odds of this being a 1-ft cavity in any 6 feet of well bore below the top of rock are 100%, based on data from five piezometer wells.

Some cavities in the Chickamauga Limestone do not transmit large quantities of water. Wells 800 and 804 encountered filled cavities 14 ft and 7 ft high; both wells have hydraulic conductivity and transmissivity values smaller than the population mean minus one standard deviation. These cavities may represent fossil flow paths that have been captured by newer routes. It is also possible, however, that these wells would produce large amounts of water if cavity-fill materials were removed. The water table is 17-32 ft above the top of the cavity in well 804; in well 800, the water table is within the cavity most of the year but is about 15 ft above the cavity at the time of the seasonal high.

The actual yield of water from wells in WAG 11 is unknown. Initial yield depends mainly on aquifer transmissivity near the well, but a sustained water yield at the same rate requires an adequate transmissivity and specific yield within a radius of at least several hundred feet. The mean transmissivity of the aquifers is low, and, as is discussed later, various estimates for storativity (coefficients of storage) indicate a low specific yield. Aquifer tests would be needed to determine the actual initial and sustained yields of the wells.

Slug test results in WAG 11 show that all piezometer wells have a measurable response to a slug and, thus, that water-producing zones are very common in this area, as in other areas near ORNL. It is also significant that there are no detectable differences between the responses of wells in regolith and wells in rock and between the responses of Chickamauga wells and Rome wells. Previous authors have generally agreed (McMaster 1967, pp. 12-13, for example) that openings along fractures are not substantially enlarged in the Rome Formation because the rock is relatively insoluble, and that this rock unit is a poor aquifer. This conclusion is incorrect in the WAG 11 area; the reasons may include an unusually large number of fractures caused by proximity to the Whiteoak Mountain fault and an unusually large amount of groundwater flow. The thick regolith near the Whiteoak Mountain fault and the similar regolith thickness for Rome and Chickamauga suggest that the soil-forming process has been greatly aided by a large number of closely spaced fractures in the rocks.

There is no apparent spatial correlation of hydraulic conductivity and transmissivity values in WAG 11. Nearby wells in several areas have similar values, but other nearby wells have values that differ by an order of magnitude or more (Fig. 4 and Table 4). This same condition has been noted in all areas near ORNL where hydraulic conductivity values are available for nearby wells. Similarly, Luxmoore et al. (1981, p. 690) found no spatial correlation for infiltration tests with a 6-ft spacing.

The permeability of the rocks at deeper levels has not been tested in WAG 11. However, the analysis of hydraulic conductivity values in other areas from packer tests in deep coreholes shows a statistically significant decrease in aquifer permeability below a depth of 65-100 ft. The geometric mean hydraulic conductivity below this level is 0.0021 ft/d, and the two standard deviation range is 0.00011-0.039 ft/d. Conditions in WAG 11 are probably similar, although the change may occur at a somewhat deeper level.

2.3.4 Aquifer Water Storage

In fractured rock, storativity is approximately equal to the porosity of the aquifer (the volume of open fractures in a unit volume of rock). In the ORNL area, storativity probably has a lognormal distribution and a large range, but various previous studies have estimated the mean value of this parameter. Recent slug tests on 250 piezometer wells near ORNL suggest that the range in storativity is 1×10^{-2} to 1×10^{-6} but that the mean may be about 1×10^{-4}. More accurate measurements were made by Smith and Vaughan (1985, pp. 141, 144), using two aquifer tests and the data from six observation wells in each test; they obtained geometric mean values for aquifer storativity of 1×10^{-3} and 4×10^{-3}.

Another approach to the estimation of aquifer storativity can be made by use of a lumped-parameter model. Viscous flow through open fractures is similar to flow between parallel plates in a Hele-Shaw model. The Navier-Stokes equation for laminar flow and equilibrium conditions in a Hele-Shaw model is:

$$T = gb^3/12v,$$

where T is aquifer transmissivity (ft^2/sec), g is acceleration of gravity (32.2 ft/sec^2), b is aperture (ft), and v is kinematic viscosity of water (1.2×10^{-5} ft^2/sec at 60°F). Since the geometric mean transmissivity for aquifers near ORNL is 1.9×10^{-5} ft^2/sec, the aperture of the fracture that supplies water to a hypothetical average well is 4.4×10^{-4} ft or 0.0052 in. The average piezometer well has a well-bore diameter of 0.54 ft and a depth of 23 ft, including 10 ft of regolith; the mean volume of rock represented by the well bore is 3.0 ft^3. One dimension of the fracture volume is aquifer thickness (calculated geometric mean = 13 ft), the second dimension is well-bore diameter, and the third dimension is aperture. Mean fracture volume in the space represented by the well bore thus is 0.0031 ft^3. The ratio of these volumes shows that the average porosity (and aquifer storativity) of the uppermost part of the rock is 0.0010.

The porosity of 0.10% calculated from the lumped-parameter model is reasonably close to the average porosity of 0.25% determined by Smith and Vaughan (1985). It is probably also significant that these values are approximately the same as the 0.21% volume of macropores and mesopores calculated from soil infiltration tests (Watson and Luxmoore 1986, p. 581). If mean porosity is 0.0015, then each 10-ft thickness of aquifer in the WAG 11 area stores 0.18 in. of water, and the 25 feet of seasonal change in water level near the center of the WAG represents a change in aquifer storage of 0.45 in. of water. The exact amount of groundwater stored below WAG 11 cannot be determined. However, if nearly all fresh groundwater occurs in the upper 100 ft, total groundwater storage might be about 2 in. Most of the differences in the lowest base-flow characteristics of streams draining limestones, sandstones, and shales are caused by differences in the water storage capacity of these rocks. Thus, there may be local differences in the storage capacity of aquifers within WAG 11 as well as among various other areas near ORNL.

2.3.5 Flow Paths and Groundwater Movement

The water table occurs in regolith in part of the WAG 11 area and below the top of bedrock in other parts of the area (Fig. 6). In both types of aquifer material, groundwater flow directions are determined by the orientation of local openings and by the direction of the hydraulic gradient within each opening. The network of openings permits both lateral and vertical flow, and groundwater flow paths may resemble stairsteps in both plan and section views. In other words, groundwater may move laterally along an opening until it reaches an intersection where it may then move in an orthogonal direction, either laterally or vertically. Changes in aperture, which determines hydraulic conductivity, probably occur at every intersection, and flow paths may split or join at these points. Splits are probably more common near recharge areas, whereas joins are more common near discharge areas. These characteristics mean that flow paths are complex. Both vertical flow and lateral flow may occur along any individual opening as well as at intersections, and lateral flow in different directions may occur at different levels in the aquifers. At higher elevations in the WAG 11 area, lateral flow paths lead toward nearby seeps, springs, and streams; most groundwater is discharged before reaching the lower elevations near WAG center.

Any water-table contour map in the ORNL area must be interpreted cautiously because local groundwater flow is not necessarily in the direction of the maximum apparent gradient shown by the map. However, the water table map (Fig. 7) for WAG 11 shows that groundwater generally moves toward WAG center from all directions. The closed water-table depression, centered at piezometer well 800, indicates that groundwater then moves vertically downward to a conduit at some deeper level in the aquifer. The deeper conduit probably trends southwestward along the valley of the unnamed northern tributary to Bear Creek, as is suggested by the 800-ft contour near the southwestern side of the WAG; shallow groundwater in this part of the WAG apparently follows a similar route along the valley. The exact location and trend of the deeper conduit cannot be determined. The closed water-table depression is generally in the Chickamauga Limestone on the northern side of the Whiteoak Mountain fault. The conduit may or may not follow this fault to Bear Creek. None of the groundwater that leaves the WAG 11 area follows the valley of the southern unnamed tributary to Bear Creek, but some groundwater is discharged to this stream in the WAG area.

The similar water table elevations on the north and south sides of the Whiteoak Mountain fault (Fig. 6) show that the fault is not a barrier to groundwater at the level of the water table, and thus is not a barrier in the regolith. Also, the position of the closed water-table depression, north of the fault, suggests that the fault itself is not a master conduit.

The rate of groundwater flow toward the closed water-table depression near the center of WAG 11 can be calculated from the equation:

$$Q = 7.48KbIL,$$

where Q is rate of flow (gal/d), K is hydraulic conductivity (ft/d), b is aquifer thickness (ft), I is hydraulic gradient (dimensionless), and L is length of section (ft). The length of the closed 800-ft contour is about 2300 ft, the average gradient across this contour is 0.028, mean hydraulic conductivity is 0.13 ft/d, and aquifer thickness is 100 ft. Thus, an average 6300 gal/d or 4.3 gal/min of groundwater flow into this depression from the surrounding area and then move downward into the deeper conduit. This amount of water, however, does not include infiltration and recharge within the area enclosed by the 800-ft contour. If 8 in./y of water recharges the aquifer in this 6.2-acre area, then total groundwater flow at the center of the depression is about 9900 gal/d or 6.9 gal/min. The maximum possible recharge in the area of the depression is the 25 in. of mean annual precipitation that is not consumed by evapotranspiration. This amount of water is equivalent to a total groundwater flow rate of about 18,000 gal/d or 12 gal/min.

The calculations above show that the mean hydraulic gradient and aquifer transmissivity in WAG 11, as in other areas near ORNL, represent small rates and quantities of groundwater flow below the water table. This is good evidence that most groundwater flow paths are short and that most aquifer discharge occurs along flow paths that trend laterally from the point of recharge to the closest seep, spring, or stream. Thus, the majority of groundwater is discharged to streams within the WAG; minor amounts leave the area along flow paths that lead toward Bear Creek. If 25 in. of annual infiltration are assumed for the 30.4-acre area of WAG 11, 32% (8.0 in.) of this water reaches the water table, 13% (3.2 in.) is discharged to streams within the WAG 11 area, and 19% (4.8 in.) leaves the area as groundwater flow.

2.3.6 Chemical Characteristics of Groundwater

The composition of groundwater is controlled by many factors, including the chemical content of recharge waters, interactions with the regolith and with bedrock, residence times, and mixtures or dilutions with waters from other flow paths. Also, the concentration of many constituents is not constant but varies throughout the year, apparently depending on groundwater flow rates. Chemical analyses are not available for WAG 11, but the characteristics of the major constituents can be estimated from analyses of groundwater in other areas near ORNL.

Most groundwater from shallow wells is a nearly neutral to moderately alkaline (pH 6.5-8.1), calcium-bicarbonate type. Magnesium concentration typically is about the same as sodium and is about half the concentration of calcium (Stockdale 1951, p. 79; Davis et al. 1984, pp. 157-170; and Webster and Bradley, 1987, Table 10).

A variation in the type of water from shallow wells is shown by samples from five wells 50-100 ft deep (Stockdale 1951, p. 79). This water, like that of the more typical type above, is neutral to slightly alkaline (pH 6.7-7.8), but sodium content is approximately equal to calcium plus magnesium. These characteristics suggest that soluble sodium salts are more readily available for solution in some areas than in others, especially at levels a little deeper than those of the shallowest wells.

A distinctly different groundwater is reported by Webster and Bradley (1987, Table 10) from six wells 100-200 ft deep. This is a sodium-carbonate or sodium-bicarbonate type water with a pH of 8.5-10.5, a sodium content of 60-300 mg/L, and a calcium plus magnesium concentration of less than 12 mg/L. These characteristics apparently result from ion exchange (calcium and magnesium for sodium) along deeper flow paths and suggest that much less water moves along these deeper paths than moves through fractures near the top of bedrock. All three of the chemical types that characterize water from wells up to 200 ft deep generally have a dissolved solids content of less than 500 mg/L and the concentration in water from most wells is 300-400 mg/L.

A much higher concentration of dissolved salts is found in water from wells 500-1500 ft deep (Haase et al. 1987; Switek et al. 1987); total dissolved solids contents as high as 300,000 mg/L have been reported. This water is acidic and has (1) a high percentage weight of chloride and an equivalent weight of sodium less than that of chloride, (2) enriched calcium, magnesium, strontium, and bromide contents, and (3) relatively low concentrations of bicarbonate, sulfate, and nitrogen. In terms of membrane-filtration theory, these waters are membrane concentrated and connate. It is very unlikely that these analyses represent circulating groundwater, but there is not yet a preponderance of evidence to support the hypothesis.

2.4 Environmental Monitoring

A review of the existing information on WAG 11 indicates that no wells were installed in the vicinity of the White Wing Scrap Yard prior to 1987. There is also no record of any sampling being conducted of the surface water drainage in the area.

As a result of the designation of the Scrap Yard as a SWMU in the RFA (1987), a number of piezometers (14) were installed in late 1987 to obtain information required to locate water quality wells to establish the presence or absence of contaminant migration via the groundwater pathway. The location of these piezometer wells is shown on Fig. 2.

Based on water level measurements in the new piezometer wells, tentative locations have been established on the WAG 11 perimeter for 11 water quality wells. Although there is an indication (see Section 2.3.5) that groundwater flow may follow a preferred pathway to the west, no water quality wells have been included within the WAG; however additional piezometer wells may be installed at a later date to establish flow paths within the WAG (Baughn and Anderson 1988).

3.0 ADDITIONAL INFORMATION NEEDS FOR WAG 11

WAG 11 was recommended for an Remedial Investigation (RI) Plan on the basis of the past history of the site, the presence of small pieces of scrap metal on the surface, and the analytical results obtained during preparation of the RFA (ORNL 1987a). Although a detailed review of the existing information on the site (see Section 2) indicated that sufficient information was available to describe the current status of the site and its geology and hydrology, there are areas where additional information might be required in the event that water quality monitoring wells detect contamination. The following sections indicate the nature of the information that might be required and suggested methods for obtaining this information.

3.1 Source Term

Although essentially all of the large scrap has been removed from the scrap yard, a visual examination indicates that the surface of the northern portion is covered with a large number of small pieces of scrap metal and plastic (such as metal couplings and valve parts, electrical connectors, and chunks of lucite or plastic). There are also a few large concrete masses (shielding blocks) and some rusted barrels remaining at the site. Although records do not indicate the presence of buried scrap, it is possible that limited burials may have occurred during past operations or during initial site cleanup.

The major concern regarding the source term for WAG 11 appears to be a determination of the amount of radioactivity and hazardous materials remaining at the site. Based on existing memoranda regarding site cleanup (Clark 1971), it appears that some radionuclide contamination remains at the site. This was confirmed by the aerial survey conducted in 1974 (Burson 1976). It is also possible that hazardous waste constituents are present; the scoping surveys performed by Morrison and Cerling (1987) have indicated the presence of some metals in the streambeds draining the site, and water samples removed from the piezometer wells have indicated the presence of organic compounds (see Section 1.4).

Based on available information, it appears that the major sources of contamination have been removed from WAG 11; however, contaminated site soils remain. A soil sampling program will be required to determine the extent and nature of the residual soil contamination. As a part of this investigation it is suggested that a few shallow test pits be excavated to determine if the small pieces of scrap seen on the surface at the site represent the majority of the scrap materials remaining. In addition, some effort should be devoted to locating areas where scrap may have been buried.

For WAG 11, the application of geophysical techniques such as electromagnetics and magnetometry may be applicable (Selfridge 1987a, Table 1). Magnetometry will detect the presence of ferrous metals (iron and steel) which may be the predominant waste form in this area. The complementary electromagnetic techniques are able to detect metals based on the amount of available surface area of the target and would therefore aid in detection of the nonferrous materials. The quadrature component of the received electromagnetic field can also help identify contaminant plumes if they are present. A low-frequency terrain-conductivity instrument with a 3.66-m spacing between the transmitter and the receiver would be adequate to detect a single 45-gal oil drum down to a depth of approximately 3.7 m (Koerner et al. 1982). Both instruments are operable by a single trained technician under a geophysicist's supervision. A magnetic gradiometer would be advisable over a total field instrument in this survey to enhance only the near-surface anomalies and to filter out regional and diurnal changes in the earth's magnetic field. Additional details on the theory of operation and field methods for geophysical techniques are provided in Benson (1984), Breiner (1973), McNeill (1980, 1983, and 1985) and Selfridge (1987b).

These surveys might best be conducted using aerial methods rather than walk-over procedures. Magnetic, electromagnetic and other equipment can be installed in a helicopter for high resolution (50- to 100-ft flight line spacing) surveys. The use of aerial methods would minimize the interference caused by the small pieces of metal that currently are scattered on the surface of WAG 11. Although the aerial survey would provide a rapid surveying method, it might only be economical if additional areas were identified that needed similar surveying techniques. Similar problems in locating buried objects and trenches exist in WAGs 3, 4, and 5, and it might be possible to justify the additional cost by conducting aerial surveys of a number of WAGs at the same time.

3.2 Geology and Hydrology

Depending on the results obtained by the water quality monitoring wells, it may be necessary to obtain more detailed information on the geology and hydrology of WAG 11. This information may include an improved delineation of faults and cavity systems near the center of WAG 11 in order to obtain a better understanding of groundwater occurrence and flow paths in this area. Alternative exploration procedures include

(1) the drilling and testing of additional piezometer wells, (2) seismic refraction surveys, and (3) electrical resistivity surveys. All three procedures are time consuming and thus are relatively expensive. The most expensive technique, but the one with the most certain results, is well drilling. An additional 8-16 piezometer wells should permit a much improved definition of the locations of faults and cavity systems. Other information will include groundwater flow paths, flow directions, and velocities. Seismic refraction surveys are less expensive but are less certain to produce the desired results. Analyses of data from 4-6 survey lines should show the type of bedrock, depth to bedrock, depth to water table, and lateral positions of faults and cavities. Electrical resistivity surveys may produce similar information but are less reliable because of possible interference and anomalous measurements that may be caused by buried scrap metal, perched water tables, unmapped changes in lithology, and unmapped faults. Resistivity surveys would be expected to be about 50% less costly than seismic surveys.

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